DESIGN AND IMPLEMENTATION OF A KNOWLEDGE-BASED SYSTEM FOR ANTIFRICTION BEARING SELECTION

by

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Design and Implementation of a Knowledge-Based System for Antifriction Bearing Selection

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|| Shri Ganeshaya Namah ||

Dedicated to my parents

CERTIFICATE

This is to certify that the work contained in this thesis entitled "**Design and Implementation of a Knowledge–Based System for Antifriction Bearing Selection**", by **Narendra Kumar Gupta**, has been carried out under our supervision and that this work has not been submitted elsewhere for the award of a degree.

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Narendra Kumar Gupta

ABSTRACT

A computer-aided knowledge based system, BEARSEL, is developed for the selection of antifriction bearings. For each bearing type, a data base which contains boundary dimensions, basic load ratings, limiting speeds, mass, company name and load factors of bearings is created. Knowledge about bearing type suitability, seals, lubrication, and fits and tolerances is also stored in separate data bases. Inputs required by the system are, speed, load, reliability, service life, operating temperature, dimensional constraints and desired level of few operating conditions.

Based on given inputs, system selects and ranks suitable bearing types and on selection of one type by the user, optimum size bearings are suggested. Recommendations are made for shaft and housing fits, lubrication and sealing methods. The system has six modules : Data-Input/Edit, Selection, Installation, Update, Print and Exit.

The system is adaptive and easily updatable. It is menu driven and user friendly, and is implemented on IBM compatible PC computer using DBase IV.2.

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NOMENCLATURE

a_1	Life adjustment factor for reliability
a_2	Life adjustment factor for material
a_3	Life adjustment factor for operating conditions
a_{23}	Life adjustment factor for material and operating conditions
B	Bearing width, mm
C	Dynamic load rating, N
C_o	Static load rating, N
C_{req}	Required dynamic load rating, N
c_p	Constant of contact pressure
D	Bearing outside diameter, mm
d	Bearing bore diameter, mm
d_w	Rlling element diameter, mm
e	Bearing factor
F_a	Axial bearing load, N
$F_{a_{max}}$	Admissible axial bearing load, N
F_r	Radial bearing load, N
FT	Temperature factor
f_s	Index of static stress
i	Number of rolling element rows
L_{10}	Basic rating life in millions of revolutions
L_{10h}	Basic rating life in operating hours
L_{10s}	Basic rating life in millions of kms.
L_{na}	Adjusted rating life
l_{eff}	Effective roller length, mm
n	Rotational speed, rpm
n_m	Mean bearing speed,rpm
P	Equivalent dynamic bearing load, N
P_m	Mean bearing load, N
P_o	Equivalent static bearing load, N
p	Exponent for life equation
$p_{o_{perm}}$	Permissible Hertzian contact pressure
q	Percentage of cycle/total time, %
SF	Shock factor
T	Operating temperature, ^oC

X	Radial load factor for dynamically stressed bearing
X_o	Radial load factor for statically stressed bearing
Y	Thrust/Axial load factor for dynamically stressed bearing
Y_o	Thrust/Axial load factor for statically stressed bearing
z	Number of rolling elements in a row
α_o	Contact angle
δ_b	Deformation, mm
α_o	Contact angle
μ	Coefficient of friction for bearing
ν	Kinematic viscosity of lubricant at specified temperature, mm^2/s
ν_1	Required Kinematic viscosity of lubricant at operating temperature, mm^2/s
ζ, η	Constants in viscosity equation

Chapter 1

Introduction

Selection of engineering components and products from manufacturers' catalogues is an area which is ideally suited to computerization. The major issues are as follows :

- The amount of technical information used to describe components and their performance characteristics is usually very large.

- While some data are in numeric and text format, data are also expressed as graphical charts or even as empirical relationships.

- Component and product selection inherently is a multi-stage and iterative decision process, and it requires performing some analysis at various stages of process to verify suitability in a specific application. Frequently, this can be a complex and tedious job to complete manually.

- The selection process often requires some degree of subjectivity while making choices.

- Various data, if suitably configured, may be stored as records in data files, rapidly accessed and retrieved using searching algorithms. Therefore, the scope for establishing heuristic rules from experienced engineers, building up a knowledge base and applying expert system techniques, lead to obvious advantages for the less experienced engineers exploiting such systems.

Of the engineering components, selection of suitable bearings for a given mechanical application constitutes a significant problem for a mechanical engineer. It is a complex problem and shares most of the factors mentioned above. Further, while the knowledge in this field is reasonably vast, expert opinion differ significantly. There is a need for computerized knowledge-based bearing selection system as a tool to systemize, conserve and spread this knowledge. Such a computerized selection system would offer the following advantages :

- A rapid selection procedure resulting into reduced time and cost.

- The best available bearing is readily identified both from technical considerations as well as commercial considerations (costs and availability).

- All bearing variants can be considered without prejudice.
- Optimum bearings can be specified without bias, thus impartiality of selection is maintained not only between manufacturers but amongst bearing types also.
- The use of 'standard' catalogue bearings is encouraged rather than the design and manufacture of 'specials'.
- Accuracy and reliability of results are improved.
- The system could be linked directly to other expert systems, which would further enhance the overall design process.

Rolling bearings are used in a variety of applications, ranging from gaint turbines to iny electric motors. Generally speaking, the function of a bearing is to take up loads on . shaft so that the shaft is able to rotate freely without dislocation or damage. There are wo main types of rolling bearings :

1. Roller bearings
2. Ball bearings

According to main load direction, bearings may also be classified as radial and thrust earings. Bearing types can be subdivided into several subtypes, so the bearing taxonomy night be depicted as a tree (Fig. 1.1). This tree is a generalization vis-a-vis specialization ierarchy with property inheritance, where each node denotes a certain class of bearings.

.1 Literature Review

ome basic research and software developement on bearing selection has already been arried out and are also in progress - both within academia and by bearing manufacturers hemselves [1].

Many of the major manufacturers, with prime interest of promoting their own products, ave developed selection software packages for potential engineering customers and 'in-ouse' use by their technical personnel. For example, the Swedish manufacturer, SKF as developed a system called **Cadalog**, the West German company, FAG has recently ntroduced its equivalent program called **WAS** and the Timken company has produced **elect-a-nalysis** [1].

Although these systems are relatively advanced, they do have some drawbacks. Be-ause they only deal with an individual manufacturer's products they may not be totally bjective in the selection procedure.

The preliminary work on computer aided selection procedure for rolling element bear-ngs was done by J.Ellis [2] in 1974. The program developed was for use in conjunction ith the manufacturer's (SKF) catalogue and computer was used only for calculations nvolved to check the suitability of previously selected bearing.

Ben O. McCutchan, Jr [3] published precised information based on experience and engineering judgement to select ball bearings. Similarily, J.K.Bailey, Jr [4] provided information for bearings operating at high speed.

Fagan [5] has reported the developement of an expert system for bearing selection. He used heuristics for the selection criteria. His grading scheme for selection is also very subjective, using grades such as very high, high, moderate and low. The output from the expert system is just one bearing type, rather than a couple of bearing types so that the user can make a choice on the basis of cost, availability etc. Also it does not calculate and suggest actual bearing size required.

Another expert system for bearing selection called **BETSY**, developed in cooperation with bearing manufacturing company SKF, Norway is reported by G.Hasle et al [6]. It is user friendly and uses both heuristics and calculations to suggest suitable bearing type as well as actual bearing size. But it is only applicable for industrial gearboxes.

Ahluwalia J. et al [7] presented a methodology for evaluating roller bearings in terms of their suitability for a given application. The method is based on multiple attribute decision making approach called **TOPSIS** (technique for order preference by similarity to the ideal solution). They considered taper and cylindrical roller bearings only and in fact has neglected the importance and necessity of considering suitability of a bearing type for a given application.

In the area of lubrication of rolling element bearings, specifically for the selection of oil viscosity at particular operating conditions, use of nomogram is the only method which has been reported so far in the literature [8–11].

1.2 Present Work

From the above study of literature and considering the deficiency of previous work, it is clear that a computer aided system for rolling element bearing selection for general applications and having the provision for including the products of leading bearing manufacturers to ensure impartiality and totality of the selection, is not available.

In the present work an attempt is made to develope a computer-aided knowledge-based system for the selection of the rolling element bearings to overcome these drawbacks by including the bearings of leading manufacturers and widening the spectrum of applicability as far as possible for different applications.

The objective of the system is to develope a three-stage selection procedure to enable a user first to narrow down the list of suitable bearing types by shortlisting the acceptable alternatives. Although the different types of bearings are designed for special purpose, several bearing types might be suitable for a given application. This calls for an attribute priority mechanism, and a method is devised to tradeoff between alternatives to make it possible to rank the alternatives according to their suitability for the desired application hence giving the choice to the user to select best suitable bearing type.

In the second stage, on the basis of the threshold values of the pertinent attributes (e.g. dynamic load rating, limiting speed etc.), a shortlist of bearings (for the selected bearing

type) is obtained. To achieve this, the database is scanned for the pertinent attributes, one at a time, to eliminate the bearing alternatives which have one or more pertinent attribute values that fall short of the minimum required values.

Suggestions are made for shaft and housing fits, lubrication and sealing methods in the final stage.

An interactive software package has been developed to assist an user to establish his/her priorities. Most of the design attributes (discussed in chapter 2) are considered in the selection procedure, either directly or indirectly. The system is completely menu driven and user friendly and is implemented on an IBM PC computer using dBase IV.2 . A PC is deliberately choosen because of its wide spread acceptance, flexibility and portability.

1.3 Organization of Thesis

In **chapter 2**, the system analysis is presented. The knowledge acquired from the catalogues, literature and expert opinions is represented using rules of non-algorithmic nature, mathematical expressions and tables.

In **chapter 3**, the design and implementation of the system on the computer is discussed. Flow of information and data, program algorithms and system architecture are briefly described.

In **chapter 4**, the results obtained by running the system for known applications are presented alongwith a discussion on the system performance.

In **chapter 5**, a conclusion is drawn and suggestions for future work are given.

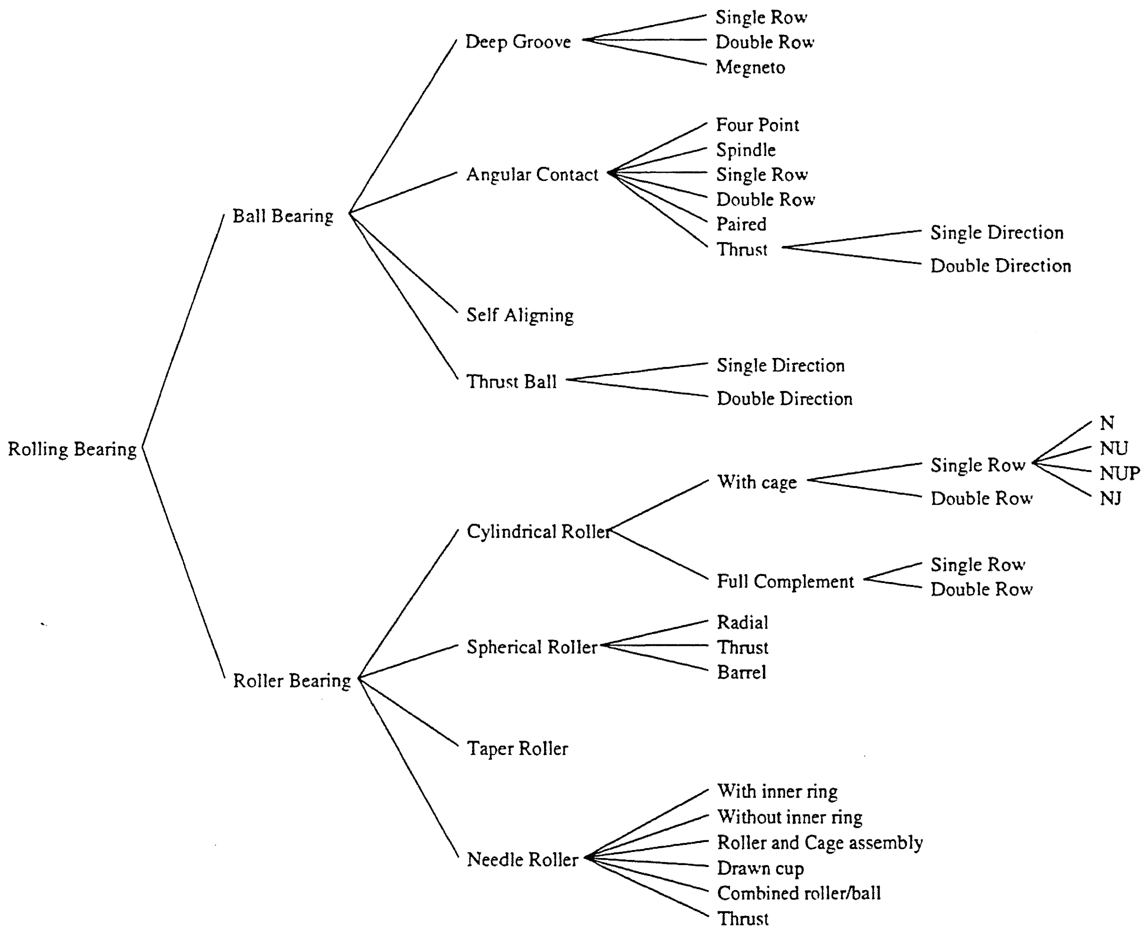


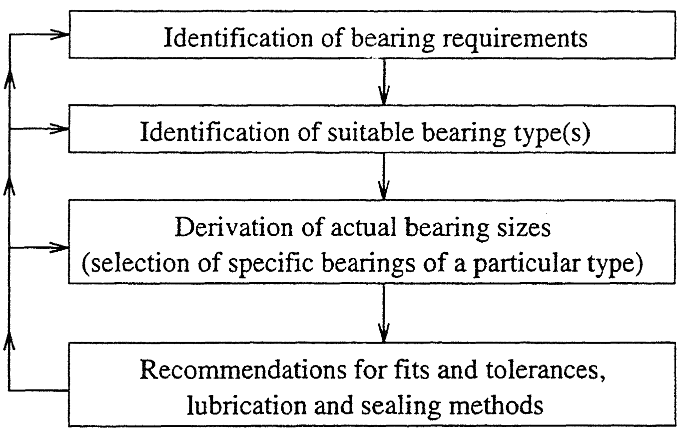
Figure 1.1: Bearing type taxonomy

Chapter 2

System Analysis

2.1 Introduction

The complete process of bearing selection can be summarised as follows :



This process is iterative. Heuristics give reasonable alternatives at each step. Pruning of the given alternatives is done after selection of bearing type by geometry, rating life and analysis considerations applied to the relevent bearings. The brief analysis of various steps involved in the process of selection is given in the following sections.

2.2 Identification of Bearing Requirements

The identificaton of various requirements and functions to be fulfilled by a bearing for a particular application is the first important step. They are defined in the form of factors. Their proper values, relative priorities and complexities play an important role in the process of selection. They are discussed in next section.

2.3 Factors for Identification of Possible Bearing Type(s)

Each type of bearing has charecteristic features which make it particularly suitable for certain application. Several bearing types might be suitable for a given application. However, no such hard and fast rules exist for the selection of bearing types since several factors must be considered and assessed in relation to each other. The most important factors on which choice of bearing depend are listed below.

- Bearing loads,
- Vibration and shock loads,
- Rotational speed,
- Available space,
- Operating temperature,
- Shaft alignment,
- Permissible noise,
- Precision requirements,
- Rigidity,
- Availability and cost,
- Friction torque,
- Axial displacement,
- Mounting and dismounting.

Details of greatest importance in deciding type of bearing according to each factor are as follows :

2.3.1 Bearing Loads

Magnitude

Generally, roller bearings can carry greater loads than ball bearings of same external dimensions and are often the only choice for heavy loads and large diameter shafts. Ball bearings are mostly used for light and medium loads.

Direction (radial, axial, or combined)

Some of the bearing types can carry only radial loads, while some are only suitable for axial loads either in one direction or in both directions. Some can carry combined loads (radial and axial loads acting simultaneously). The ability of a bearing to carry an axial load depends on its angle of contact. The greater this angle the more suitable is the bearing for axial loads. Where the axial component of the combined load is large, a separate thrust bearing can be provided for carrying the axial load independently of the radial load. The suitability of all bearing types with respect to different load types is shown in Table 2.1 [10] and [12–16].

2.3.2 Vibration and Shock load

In addition to other loads, the presence of shock load and vibration also influence the choice of suitable bearing type. The suitability of bearing types in this respect is shown in Table 2.1 [3,10,12].

2.3.3 Rotational Speed

The speed of rotation of a rolling bearing is limited by the permissible operating temperature. Bearings with low frictional resistance and correspondingly low internal heat generation are most suitable for high rotational speeds. For radial loads, the highest bearing speeds are obtainable with deep groove ball or cylindrical roller bearings, and for combined loads with angular contact ball bearings (see Table 2.1).

2.3.4 Available Space

In many instances at least one of the main dimensions (usually the bore diameter) is predetermined by the machine design. Deep groove ball bearings are normally selected for small diameter shafts whereas, cylindrical roller and spherical roller bearings can be considered for large diameter shafts. If radial space is limited then bearings with small sectional height e.g. needle roller bearings etc. must be considered. Where axial space is limited, some series of single row cylindrical roller and deep groove ball bearings for radial and combined loads and, for axial loads, needle roller thrust and thrust ball bearings may be used.

Bearing Type	Load Capacity				Speed	Load Ratio	Locating
	Radial	Axial	Combined	Shock	(max.)	F_a/F_r	Capacity
ACBB1	G	< G	G	F	28000	-	G
ACBB2	G	< G >	G	F	15000	-	G
ACBB3	G	< G >	G	F	22000	-	G
ACTBBSD	U	< G	P	P	4000	>> 2.13	-
ACTBBSD	U	< G >	U	P	16000	-	-
BRB	E	< P >	F	G	7500	-	F
CRB1	F	U	U	G	24000	-	U
CRB3	F	< P	P	G	20000	<< 0.2	F
CRBDR	E	U	U	G	19000	-	U
CRTB	U	< G	U	E	4300	-	-
DGBB1	F	< F >	F	P	48000	-	G
DGBB2	F	< F	F	P	22000	<< 0.3	G
FPCBB	F	< G >	G	P	17000	>> 1.27	G
MB	F	< F	F	U	40000	-	U
NRB1	G	U	U	E	36000	-	U
NRB4	G	< P >	F	G	25000	<< 0.25	G
NRB5	P	< G	F	G	9500	-	F
NRTB	U	< G	U	E	4800	-	-
SABB	F	< P >	P	G	38000	-	F
SB	G	< G	G	P	80000	-	G
SRB1	E	< F >	G	E	9000	-	G
SRTB	P	< E	F	G	2600	>> 1.82	-
TBB1	U	< F	U	U	9500	-	-
TBB2	U	< F >	U	U	7000	-	-
TRB	E	< G	G	E	13000	-	E

* E excellent; G good; F fair; P poor; U unsuitable
* < single direction; <> double direction; >> greater than; << less than
* For full name of Bearing Type see Table 3.2

Table 2.1: Capabilities of different bearing types [10–16]

2.3.5 Operating Temperature

All rolling bearings can be used at temperature upto 120 ^oC. At higher temperatures, the hardness of bearing materials and hence load carrying capacity reduces. For this, heat treated (stabilised for higher temperature) bearings are selected.

2.3.6 Shaft Alignment

In certain applications where the shaft can be misaligned relative to the housing, bearings capable of accomodating such misalignment are required. Misalignment can, for example, be caused by shaft deflection under load, bearings fitted in housings positioned on separate bases at a large distance or when it is impossible to machine the housing seatings in one setting. The permissible alignment angles and relative self aligning capabilities for various bearing types are listed in Tables 2.2 and 2.3 respectively [10].

Bearing type	Alignment angle
Self aligning ball bearings	4^o
Barrel roller bearings	4^o
Spherical roller bearings	2^o
Spherical roller thrust bearings	0.5^o–2^o
Deep groove ball bearings	$5' - -15'$
Cylindrical roller bearings	$2' - -7'$
taper roller bearings	$1' - -3'$

Table 2.2: Permissible alignment angles [10,12]

2.3.7 Permissible Noise

Whilst rolling bearings have an intrinsically low noise level there are applications, for example electric motors running in hospitals, offices and homes, where this is an important factor in bearing selection. Deep groove ball bearings are normally the best choice. Suitability of various bearings types is listed in Table 2.3 .

2.3.8 Precision Requirements

Rolling bearings with a higher degree of precision than normal are required for shafts where stringent demands are made on running accuracy, e.g. machine tool spindles and also usually for shafts rotating at very high speeds. Suitability according to running accuracy of various bearing types is listed in Table 2.3 .

Bearing Type	Factors							
	Running Accuracy	Self Aligning Capacity	Radial Rigi-dity	Axial Rigi-dity	Running Quiet-ness	Low Fric-tion	Mainte-nance	Cost
ACBB1	E	P	G	G	G	P	G	G
ACBB2	E	U	G	G	G	G	P	F
ACBB3	E	U	G	E	G	F	P	F
ACTBB	E	U	E	G	P	E	P	G
BRB	G	E	F	G	U	F	P	P
CRB1	E	F	G	U	F	E	E	F
CRB3	G	F	G	U	U	E	E	P
CRBDR	E	F	E	U	U	G	P	P
CRTB	E	U	G	E	U	U	E	P
DGBB1	E	G	F	F	E	E	P	E
DGBB2	E	U	F	F	E	E	P	E
FPCBB	F	P	G	G	U	F	P	G
MB	E	F	F	F	E	G	G	E
NRB1	G	F	E	U	U	F	E	G
NRB4	F	U	G	F	U	F	F	F
NRB5	F	U	G	G	U	F	F	F
NRTB	F	U	U	E	U	P	E	F
SABB	G	E	F	F	U	E	P	G
SB	E	U	E	G	G	E	P	F
SRB1	G	E	F	G	U	G	P	P
SRTB	G	E	P	G	U	P	E	P
TBB1	E	U	U	G	U	E	E	E
TBB2	G	U	U	G	U	E	E	G
TRB	G	F	G	F	U	F	E	P

* E excellent; G good; F fair; P poor; U unsuitable

* For full name of Bearing Type see Table 3.2

Table 2.3: Suitability of different bearing types [10–20]

2.3.9 Rigidity

Elastic deformation in a loaded rolling bearing is very small and in most instances can be ignored. However bearing rigidity is important in some cases, e.g. for machine tool spindles. Because of the greater area of contact between the rolling elements and raceways, roller bearings deflect less than ball berings. The rigidity can be increased by suitable preloading. The suitability is listed in Table 2.3 .

2.3.10 Friction

The frictional resistance of a rolling bearing depends on several factors like bearing load, speed and the properties of lubricant. Under normal operating conditions the friction torque M (measure of frictional resistance) is obtained from the equation [10] :

$$M = \mu F d/2 \tag{2.1}$$

where :
μ = coefficient of friction for the bearing (Table 2.4)
F = bearing load, N
d = bearing bore diameter, mm

Where rubbing seals are used, having frictional resistance greater than that in bearing, seal friction is also taken into account. The suitability of various bearing types for low friction is listed in Table 2.3 .

Bearing type	μ
Self aligning ball bearings	0.0015
Spherical roller bearings	0.0018
Spherical roller thrust bearings	0.0018
Deep groove ball bearings	0.0015
Cylindrical roller bearings	0.0011
Taper roller bearings	0.0018
Angular contact ball bearings	0.0022
Needle roller bearings	0.0025
Thrust ball bearings	0.0013
Needle roller bearings	0.0025
Cylindrical roller thrust bearings	0.0040
Needle roller thrust bearings	0.0040

Table 2.4: Coefficient of friction [10]

2.3.11 Axial Displacement

The normal bearing arrangement consists of a locating (fixed) bearing and a non-locating (free) bearing. A bearing may be used as a locating, non-locating or cross-locating bearing depending on the application. The non-locating bearing can be displaced axially thus preventing cross location, e.g. by shaft expansion or contraction. The bearings having separable rings e.g. cylindrical roller (type NU and N) and needle roller bearings are particularly suitable for non locating applications. Their inner and outer rings can be mounted with interference fits. When using a non separable bearing, one of the ring should have clearance fit to allow axial freedom.

2.3.12 Mounting and Dismounting

The separable bearings are essier to install than non-separable bearings specially when an interference fit is to be used for both inner and outer rings or when frequent mounting and dismounting is required. It is easy to mount or withdraw bearings with tapered bore on tapered seating or using adapter or withdrawal sleeves on cylindrical shaft seatings. For suitability see Table 2.3 .

2.3.13 Availability and Cost

If more than one type of bearings are suitable for given application, cost and availability dominates in final selection of the bearing type.

2.4 Derivation of Actual Bearing Size

The size of a bearing to be used for a certain application is selected on the basis of its load carrying capacity in relation to the loads to be carried and the requirements regarding service life, reliability and other operating conditions. A certain degree of safety must exist to prevent excessive plastic deformation and premature material fatigue of the raceways and rolling elements.

A statically stressed bearing is rendered unserviceable by plastic deformation of rolling surfaces, whereas in dynamically stressed bearings, material fatigue causes these surfaces to flake. When necessary, wear is also taken into account. Unfavourable conditions such as dirt and lack of lubrication may increase wear and therefore clearance, to such an extent that the bearing ceases to fulfill its proper function.

2.4.1 Static Stressing

The term static stressing refers to bearing carrying a load when stationary or when subjected to small oscillating motion or rotating bearings subjected to heavy shock loads during fraction of a revolution. The load may be constant or variable. The bearings under

static load should not be stressed upto such an extent that plastic deformation causing indentation and flatened areas in the rolling surfaces, impair the rotation of the bearing.

Plastic Deformation

The plastic deformation in rolling bearing is expressed by the specific plastic deformation, defined as the ratio of sum of deformations of rolling element and raceway at one contact point δ_b to the rolling element diameter d_w. For a certain predetermined permissible magnitude of the specific plastic deformation, ratio δ_b/d_w , the plastic deformation is related to loading by following expressions [14] :

$$\text{Point contact} \qquad p_{o_{perm}} = 3300 \cdot c_p^{3/10} \left(\frac{\delta_b}{d_w}\right)^{1/5} \quad [\mathrm{N/mm^2}] \tag{2.2}$$

$$\text{Line contact} \qquad p_{o_{perm}} = 2690 \cdot c_p^{2/5} \left(\frac{\delta_b}{d_w}\right)^{1/5} \quad [\mathrm{N/mm^2}] \tag{2.3}$$

where :
$p_{o_{perm}}$ = permissible Hertzian contact pressure
c_p = constant of contact pressure according to contact conditions and can be determined from standard nomograms depending on curvature ratio, geometry and type of bearing.

Admissible Static Rolling Element Loading

Defined as permissible load Q_{perm} for which total deformation of rolling element and raceway does not exceed 0.01% of rolling element diameter, d_w, ensuring quiet running and full fatigue life of bearing. For $\delta_b/d_w = 0.0001$, Q_{perm} is given by [14] :

$$\text{Point contact} \qquad Q_{perm} = \left(\frac{p_{o_{perm}}}{c_p}\right)^3 d_w^2 = k_s\, d_w^2 \tag{2.4}$$

$$\text{Line contact} \qquad Q_{perm} = \left(\frac{p_{o_{perm}}}{c_p}\right)^2 d_w \cdot l_{eff} = k_s\, d_w \cdot l_{eff} \tag{2.5}$$

where :
l_{eff} = effective roller length, mm
Factor $k_s = \left(\frac{p_{o_{perm}}}{c_p}\right)^3 = \frac{1.43 \cdot 10^8}{c_p^{2.1}}$ [N/mm²] for point contact

$= \left(\frac{p_{o_{perm}}}{c_p}\right)^2 = \frac{1.82 \cdot 10^5}{c_p^{1.2}}$ [N/mm²] for line contact

Factor k_s depends upon c_p hence, curvature of rolling element and rolling path under highest stress. For different bearing types following approximate values may be considered For Deep groove ball and Angular contact ball bearings $k_s = 70$, for Thrust ball bearings and Roller bearings $k_s = 60$ & 200 respectively.

Static Load Rating C_o

The static load rating for bearings made of hardened bearing steel represents the load at which, under defined operating conditions, the maximum rolling element load Q_{max} equals the admissible rolling element load Q_{perm} or load which will produce permanent deformation of the rolling element and raceway on the most heavily stressed rolling element/raceway contact of 0.0001 times the rolling element diameter. In radial bearings, it corresponds to purely radial load and in thrust bearing to an axial load [14].
For radial and angular contact ball bearings,

$$Q_{max} = \left(\frac{5.0 \cdot C_o}{i \cdot z \cdot \cos\alpha_o}\right) \tag{2.6}$$

where :
i = number of rolling element rows
z = number of rolling element in a row
α_o = contact angle
After equting Q_{max} to Q_{perm} ,

$$C_o = \frac{k_s}{5.0} \cdot i \cdot z \cdot d_w^2 \cdot \cos\alpha_o = f_o \cdot i \cdot z \cdot d_w^2 \cdot \cos\alpha_o \quad [N] \tag{2.7}$$

similarily for radial and angular contact roller bearings,

$$C_o = \frac{k_s}{5.0} \cdot i \cdot z \cdot d_w \cdot l_{eff} \cdot \cos\alpha_o = f_o \cdot i \cdot z \cdot d_w \cdot l_{eff} \cdot \cos\alpha_o \quad [N] \tag{2.8}$$

Thrust ball bearings,

$$C_o = f_o \cdot z \cdot d_w^2 \cdot \sin\alpha_o \quad [N] \tag{2.9}$$

Thrust roller bearings,

$$C_o = f_o \cdot z \cdot d_w \cdot l_{eff} \cdot \sin\alpha_o \quad [N] \tag{2.10}$$

Here, f_o is a factor whose magnitude depends on the geometry (ratio $d_w \cdot \cos\alpha_o/T$) and type of bearing and may be obtained from stadard tables. The values of static load rating, C_o , may directly be obtained from bearing tables provided by manufacturers.

Equivelent Static Load P_o

Loads comprising radial and axial components must be converted into an equivelent static bearing load which is defined as that radial load (for thrust bearings the axial load) which, if applied, would cause the same maximum plastic deformation as the actual loads. It is obtained by means of the general equation

$$P_o = X_o \cdot F_r + Y_o \cdot F_a \quad [N] \tag{2.11}$$

where :
F_r = actual radial load [N]

F_a = actual axial load [N]
X_o = radial load factor for the bearing (Table 2.5) [N]
Y_o = axial load factor for the bearing (Table 2.5) [N]

If calculated values of $P_o < F_r$, then $P_o = F_r$ is used.

Bearing type		**Load factors**			
Radial bearings		Single row		Double row	
		X_o	Y_O	X_o	Y_O
Deep groove ball bearings		0.6	0.5	0.6	0.5
Angular contact ball bearings	$\alpha_o = 20^o$	0.5	0.42	1	0.84
	$\alpha_o = 25^o$	0.5	0.38	1	0.76
	$\alpha_o = 30^o$	0.5	0.33	1	0.76
	$\alpha_o = 35^o$	0.5	0.29	1	0.58
	$\alpha_o = 40^o$	0.5	0.26	1	0.52
Spindle bearings	$F_a/F_r \leq 1.09$	1	0		
	$F_a/F_r > 1.09$	0.5	0.46		
Megneto bearings	$F_a/F_r \leq 0.8$	1	0		
	$F_a/F_r > 0.8$	0.6	0.5		
Four point contact bear.		1	0.58		
Self aligning ball, Spherical and Taper roller bearings		0.5	$0.22 \cdot \cot \alpha_o$	1	$0.44 \cdot \cot \alpha_o$
Barrel roller bearings		1	5		
Thrust bearings		X_o	Y_O		
Angular contact ball (SD)		0.92	1		
Spherical roller bearings		2.7	1		

Table 2.5: Radial load factor X_o and axial load factor Y_o for statically stressed bearings [10,14]

Index of Static Stressing f_s

Defined as ratio of static load rating, C_o , to equivelent static load, P_o .

$$f_s = \frac{C_o}{P_o} \tag{2.12}$$

Its minimum value ensures safety from excessive local deformation. The minimum values of f_s which may be used corresponding to permissible specific plastic deformation (depending on required running smoothness, slewing angle and shock load etc) are shown in Table 2.6. Exceptionally in case of spherical roller thrust bearing, minimum index $f_s \geq 2$ is used due to lip strength because a considerable part of the load is taken by the lip of shaft washer.

Applications	f_s
Smooth, vibration - free running	0.5
Average working conditions with normal demands on quiet running	1.0
Pronounced shock loads	1.5–2.0
high demand on quiet running	2.0
Spherical roller thrust bearings	≥ 2

Table 2.6: Static index f_s [14]

For statically stressed bearings, suitable sizes can be derived by determining the equivalent static load, P_o ,and knowing the static load rating, C_o , and minimum index value, f_s.

2.4.2 Dynamic Stressing

It refers to loading of a rotating bearing. The load may be constant or variable.

Material Fatigue, Failure Probability and Distribution

Experience and experiment results show the occurance of fatigue phenomena on the operating surfaces of identical dynamically stressed bearings with similar operating conditions after different periods of operation. This makes it impossible to state the probable fatigue life of an individual bearing and can only be made for a large group of identical bearings stressed in same manner. The fatigue behavior of a large bearing group can be assessed satisfactorily by means of Weibull plot which gives statistical distribution of fatigue lives by associating running time with failure probability (proportion of bearings which have failed up to this time).

Fatigue Life or Rating Life Equation

As per ISO recommendation R281, fatigue life (rating life) of a sufficiently large number of dimensionally identical bearings is expressed by the number of revolutions or number of hours at constant speed reached or exceeded by 90% of bearings of this group before the first signs of material fatigue appear. The rating life considerably increases with decrease in bearing load and its relationship with dynamic load rating, C, and bearing load, P, for the bearings made of conventional bearing steel, operating under most favourable conditions (correct mounting and lubrication, reliable sealing, absence of extreme temperature and contamination etc.), is expressed by the rating life eqution [18] :

$$L_{10} = \left(\frac{C}{P}\right)^p \tag{2.13}$$

where :
L_{10} = basic rating life in millions of revolutions

C = basic dynamic load rating, N
P = equivelent dynamic bearing load, N
p = exponent for life eqution (3 for ball and 10/3 for roller bearings).

For bearings operating at constant speed it may be more convenient to deal with the basic rating life expressed in operating hours using the eqution [10] :

$$L_{10h} = \frac{1000000}{60 \cdot n} \left(\frac{C}{P}\right)^p \tag{2.14}$$

where :
L_{10h} = basic rating life in operating hours
n = rotational speed, rev/min

The values of L_{10} or L_{10h} corresponding to values of C/P and/or n can be found by using chart shown in Fig 2.1 . For road and rail bearings, especially wheel hub and axle bearings, it is preferable to express the life in terms of kilometers travelled and is obtained by equation [10] :

$$L_{10s} = \frac{\pi D}{1000} \left(\frac{C}{P}\right)^p \tag{2.15}$$

where :
L_{10s} = basic rating life in millions of kilometers
D = wheel diameter, m

For bearings made of materials other than the conventional steel and/or operating at abnormal conditions the rating life is expressed by adjusted rating life equation [18] :

$$L_{na} = a_1 \cdot a_2 \cdot a_3 \left(\frac{C}{P}\right)^p \tag{2.16}$$

where
L_{na} = adjusted rating life in millions of revolutions
n = index representing the difference between the requisite reliability and 100%
a_1, a_2, a_3 = life adjustment factors.

Life Adjustment Factors

a_1 : The factor for reliability is used to determine lives other than the L_{10} life, i.e. lives which are attained or exceeded with a greater probability than 90% . Values of a_1 are listed in Table 2.7 .

a_2 : The factor for material is used to take into account the effect of improvements made to conventional steel used by bearing manufacturers. Generally values of $a_2 > 1$ are used. Even higher values can be applied when special steels e.g. electro slag refined (ESR) or vacuum arc remelted (VAR) steels are used.

a_3 : The factor for operating condition is essentially determined by bearing lubrication and operating temperature.

a_{23} : The combined factor for material and lubrication, by replacing a_2 and a_3 , since both are interrelated, may be used. This can be obtained from standard charts available.

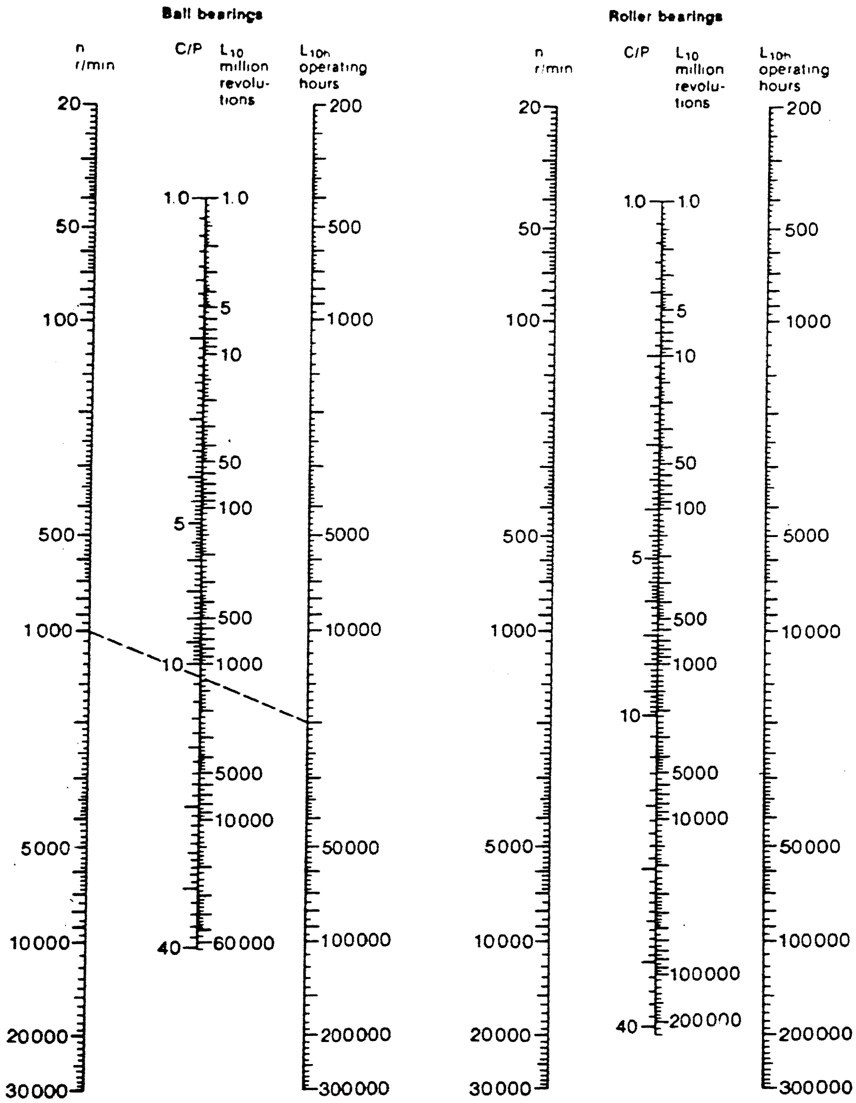


Figure 2.1: Life calculation chart [10]

Reliability %	a_1
90–94	1
95	0.62
96	0.53
97	0.44
98	0.33
99	0.21

Table 2.7: Values of life adjustment factor a_1 [10]

Requisite Basic Rating Life

When determining bearing sizes, it is essential that the required basic rating life for the application under consideration is known. This usually depends on the type of machine and the requirements regading duration of service and operation reliability. In absence of previous experience the values given in Tables 2.8 and 2.9 can be used.

Dynamic Load Rating C

It corresponds to a constant bearing load (purely radial for radial bearings and purely axial applied centrally for thrust bearings) at which a large number of identical bearings reaches a rating life of one million revolutions. For a particular bearing dynamic load rating, C, can be calculated as follows [14,15] :
For radial ball bearings :
For bearings with ball diameter $d_w \leq 25.4\,mm$

$$C = f_c \cdot (i \cdot \cos\alpha_o)^{0.7} \cdot z^{2/3} \cdot d_w^{1.8} \quad [\mathrm{N}] \tag{2.17}$$

and for $d_w > 25.4\,mm$

$$C = f_c \cdot (i \cdot \cos\alpha_o)^{0.7} \cdot z^{2/3} \cdot 3.647\, d_w^{1.4} \quad [\mathrm{N}] \tag{2.18}$$

For radial roller bearings :

$$C = f_c \cdot (i \cdot l_{eff} \cdot \cos\alpha_o)^{7/9} \cdot z^{3/4} \cdot d_w^{29/27} \quad [\mathrm{N}] \tag{2.19}$$

For thrust ball bearings :

For single & double acting thru. ball bearings ($\alpha_o = 90^o$)

$$\text{for } d_w \leq 25.4 \text{ mm} \qquad C = f_c \cdot z^{2/3} \cdot d_w^{1.8} \quad [\mathrm{N}] \tag{2.20}$$

$$\text{and for } d_w > 25.4 \text{ mm} \qquad C = f_c \cdot z^{2/3} \cdot 3.647\, d_w^{1.4} \quad [\mathrm{N}] \tag{2.21}$$

For angular contact thrust ball bearings ($\alpha_o < 90^o$)

$$\text{for } d_w \leq 25.4 \text{ mm} \qquad C = f_c \cdot (\cos\alpha_o)^{0.7} \cdot \tan\alpha_o \cdot z^{2/3} \cdot d_w^{1.8} \quad [\mathrm{N}] \tag{2.22}$$

Class of machines	L_{10h} operating hours
Domestic machines, agricultural machines, instruments, technical apparatus for medical use	300 to 3000
Machines used for short periods or intermittently: Electric hand tools, lifting tackles in workshops, construction machines	3000 to 8000
Machines used for short periods or intermittently with high operational reliability : Lifts, cranes, bales	8000 to 12000
Machines used for 8 hours per day but not always fully utilised: Gear drives for general purposes, electric motors for industrial use, rotary crushers etc.	10000 to 25000
Machines used for 8 hours per day and fully utilised: Machine tools, woodworking m/cs, machines for the engineering industry, cranes for bulk materials fans conveyor belts, printing equipments, centrifuges etc.	20000 to 30000
Machines for continuous use 24 hours per day: Rolling mill gear units, medium sized electircal machinery, compressors, pumps, textile machinery	40000 to 50000
Water works machinery, rotary furnaces,cable stradding machines, propulsion machinery for ocean vessels	60000 to 100000
Machines for continuous use 24 hours per day with high operational reliability: Pulp & paper making machines large electric machinery, mine pumps, power plant machinery, tunnel shaft bearings etc	$\approx$ 1000000

Table 2.8: Requisite basic rating life L_{10h} for different classes of machines [10,12]

Type of vehicle	L_{10s} millions of km
Wheel hub bearings for road vehicles :	
Private cars	0.1
Commercial vehicles, buses etc.	0.2 to 0.3
Axlebox bearings for rail vehicles :	
Goods wagons	0.8
Suburban stock, tramcars	1.5
Main line passenger carriages	3
Main line motor units	3 to 4
Main line diesel and electric locomotives	3 to 5

Table 2.9: Requisite basic rating life L_{10s} for road and rail vehicles [10,12]

and for $d_w > 25.4$ mm $\quad C = f_c \cdot (\cos\alpha_o)^{0.7} \cdot \tan\alpha_o \cdot z^{2/3} \cdot 3.647\, d_w^{1.4} \quad [\mathrm{N}] \qquad (2.23)$

For thrust roller bearings :
For single & double acting roller thrust bearings ($\alpha_o = 90^o$)

$$C = f_c \cdot l_{eff}^{7/9} \cdot z^{3/4} \cdot d_w^{29/27} \quad [\mathrm{N}] \tag{2.24}$$

and for $\alpha_o < 90^o$ (spherical roller thrust bearing)

$$C = f_c \cdot (l_{eff} \cdot \cos\alpha_o)^{0.7} \cdot \tan\alpha_o \cdot z^{3/4} \cdot d_w^{29/27} \quad [\mathrm{N}] \tag{2.25}$$

in which f_c is a factor whose values depend on geometry of bearing components, thier accuracy, material and type of bearing and are available in standard tables provided by manufacturers. The values of dynamic load rating, C, for each bearing are also available from bearing tables.

Influence of temperature on dynamic load rating : At elevated temperatures the hardness of bearing materials is reduced and the dynamic load carrying capacity is also reduced as a consequence. special heat treatment to ensure dimensional stability also results in a reduction of hardness. This effect is taken into account by multiplying the basic dynamic load rating, C, by a temperature factor, FT, which is listed in Table 2.10 .

Equivalent Dynamic Load P

In many bearing applications the load acts on the bearing obliquely or changes its magnitude and does not satisfy the assumption of constant load made in rating life equation. In such cases a hypothetical load (equivalent bearing load P), constant in both magnitude and direction, acting radialy on radial bearings or axially on thrust bearings, having same

Bearing temperature (^oC)	150	200	250	300
Temperature factor FT	1.0	0.9	0.75	0.6

Table 2.10: Temperature factor FT [10]

influence on the bearing life as the actual loads, is determined for rating life calculations, representing an equivelent stress.

The equivalent dynamic bearing load for constant and variable loads is calculated as follows [14] :

Constant bearing load

Radial bearings : If the magnitude and direction of the resultant load is constant, the equivelent dynamic load is obtained from the general equation :

$$P = X \cdot F_r + Y \cdot F_a \quad [\mathrm{N}] \tag{2.26}$$

where :
X = radial load factor for the bearing under dynamic load
Y = axial load factor for the bearing under dynamic load

The values of X, Y and other data required in calculation of P are shown in Table 2.11 . In case of single row radial bearings the axial load is not significant until the ratio F_a/F_r exceeds a specified value e . With double row radial bearings even light axial loads are significant. In deep groove ball bearings, subjected to axial load, a contact angle $\alpha > 0^o$ occures depending on the magnitude of load. This is taken into account by relating factors X and Y with axial load, F_a, and static load rating, C_o .
Thrust bearings : Bearings having contact angle $\alpha_o = 90^o$ can carry axial loads only whereas, for bearings having $\alpha_o \neq 90^o$, same equation, as for radial bearings, can be used with values of X and Y shown in Table 2.11 .

Variable bearing load

In many bearing arrangements, load and rotary speed change either randomly or according to work cycle and in order to calculate the equivalent bearing load, a constant mean load P_m having the same influence on the bearing (same fatigue life at mean speed) as the actual variable load is determined. The approximate constant mean load for different load and speed conditions may be obtained as follows [14] :

- When load and speed both are variable, the load and speed curves are approximated by a series of individual loads and speeds of a certain duration $q\%$ (stepped charecteristics) as shown in Fig 2.2 and the mean rotary speed, n_m, computed as weighted mean (with weightages as percentage of cycle/total time), is given by :

$$n_m = n_1 \cdot \frac{q_1}{100} + n_2 \cdot \frac{q_2}{100} + \cdots \quad [\mathrm{rpm}] \tag{2.27}$$

Bearing type $\frac{F_a}{C_o}$ *Radial bearings*		e	Single-row $\frac{F_a}{F_r} \leq e$ X	Y	$\frac{F_a}{F_r} > e$ X	Y	double-row $\frac{F_a}{F_r} \leq e$ X	Y	$\frac{F_a}{F_r} > e$ X	Y
Deep groove ball bearings	0.025	0.22	1	0	0.56	2	1	1 (for $\frac{F_a}{F_r} \leq 0.3$)		
	0.04	0.24	1	0	0.56	1.8				
	0.07	0.27	1	0	0.56	1.6				
	0.13	0.31	1	0	0.56	1.4				
	0.25	0.37	1	0	0.56	1.2				
	0.50	0.45	1	0	0.56	1				
Spindle bearings	0.025	0.4	1	0	0.44	1.42	1	1		
	0.04	0.42	1	0	0.44	1.36				
	0.07	0.44	1	0	0.44	1.27				
	0.13	0.48	1	0	0.44	1.16				
	0.25	0.53	1	0	0.44	1.05				
	0.50	0.56	1	0	0.44	1				
Angular contact ball bearings	$\alpha_o = 20^o$	0.57	1	0	0.43	1	1	1.09	0.70	1.63
	$\alpha_o = 25^o$	0.57	1	0	0.43	1	1	1.09	0.70	1.63
	$\alpha_o = 30^o$	0.57	1	0	0.43	1	1	1.09	0.70	1.63
	$\alpha_o = 35^o$	0.57	1	0	0.43	1	1	1.09	0.70	1.63
	$\alpha_o = 40^o$	0.57	1	0	0.43	1	1	1.09	0.70	1.63
Megneto bear.		0.20	1	0	0.50	2.5				
Self aligning ball bearings		$1.5 \cdot \tan\alpha_o$					1	$0.42 \cdot \cot\alpha_o$	0.65	$0.65 \cdot \cot\alpha_o$
Spherical roller bearings		$1.5 \cdot \tan\alpha_o$					1	$0.45 \cdot \cot\alpha_o$	0.67	$0.67 \cdot \cot\alpha_o$
Taper roller bearings		$1.5 \cdot \tan\alpha_o$	1	0	0.40	$0.4 \cdot \cot\alpha_o$				
Barrel roller bearings			1	9.5	1	9.5				
Thrust bearings			X	Y	X	Y	X	Y	X	Y
Angular cont. ball bearings			0.92	1	0.92	1				
Spherical roll.		1.8			1.2	1				

Table 2.11: Radial load factor X and axial load factor Y for dynamically stressed bearings [10,12,14]

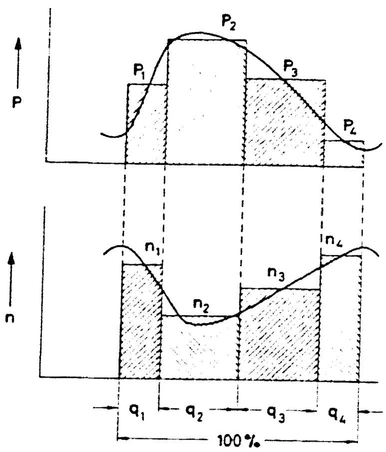


Figure 2.2: Step load approximation

and similarily the mean load P_m is given by :

$$P_m = \left(P_1^p \cdot \frac{n_1}{n_m} \cdot \frac{q_1}{100} + P_2^p \cdot \frac{n_2}{n_m} \cdot \frac{q_2}{100} + \cdots\right)^{1/p} \quad [N] \tag{2.28}$$

where P_1, $P_2, \ldots$ and n_1, $n_2, \ldots$ are the constant loads and speeds during q_1, $q_2, \ldots$ durations respectively. p is the exponent used in life equation.

- When load is variable and speed is constant,

$$P_m = \left(P_1^p \cdot \frac{q_1}{100} + P_2^p \cdot \frac{q_2}{100} + \cdots\right)^{1/p} \quad [N] \tag{2.29}$$

- When speed and direction of loading are constant and assuming load to be fluctuating linearly between P_{max} and P_{min},

$$P_m = \frac{P_{min} + 2\,P_{max}}{3} \quad [N] \tag{2.30}$$

- When the bearing load comprises a load, P_2, of constant magnitude and direction, e.g. the weight of rotor, and a rotary constant load, P_1, e.g. unbalance, the mean load is obtained by

$$P_m = P_2\left[1 + 0.5\left(\frac{P_1}{P_2}\right)^2\right] \quad [N] \tag{2.31}$$

If the variable load acts in radial direction for radial bearings and in axial direction for thrust bearings, the equivelent bearing load $P = P_m$. However, if the load acts in any other direction the equivelent load is calculated using the general equation

$$P = X \cdot F_r + Y \cdot F_a \quad [N] \tag{2.32}$$

in which, F_r and F_a are the radial and axial components of the mean load P_m or calculated separately.

Influence of shock load : In addition to the forces taken into account in calculation of equivelent bearing load, shock loads may occur in many applications. As it is very difficult to calculate accurate values of shock loads, its influence on bearing life is accounted by applying a shock factor SF to the equivalent bearing load (see Table 2.12).

Type of duty	shock factor
Almost shock free service: General purpose chain and gear drives; coal, sand and ore conveyors; rotary compressors; electric motors, auto pinions, front wheels, transmissions and rear wheels that are independently suspended, engines, farm machinery, household appliances.	1 to 1.2
Light shock service: Fans; centrifugal blowers; mixers; continuously operated cranes; belt tension devices and applications in which dead weight is the principal load; ground gears, truck and bus front and rear wheels.	1.2 to 1.5
Moderate shock service: Dryers; ball mills; trunnion wheel applications without tires; truck and bus front wheels; multiple stage pumps; milled gears.	1.5 to 2.0
Heavy shock service: Foundry shake-outs; oscillating conveyors; reciprocating compressors and pumps; crushers; hammer mills and impact pulverizers, auto and truck differentials and transaxles, press and shear flywheels.	2.0 to 3.0

Table 2.12: Shock factor FS [3]

Required Dynamic Load Rating C_{req}

The minimum basic dynamic load rating (required), C_{req}, necessary to reach the required bearing life can be calculated by using following equations :

$$\begin{aligned} C_{req} &= \left[\frac{60\, n\, L_{10h}}{10^6\, a_1}\right]^{1/p} \cdot P \cdot \frac{FS}{FT} \\ &= \left[\frac{1000\, L_{10s}}{\pi\, D\, a_1}\right]^{1/p} \cdot P \cdot \frac{FS}{FT} \end{aligned} \tag{2.33}$$

2.4.3 Admissible Axial Loads

In some types of bearings the axial load carrying capacity is not governed by the fatigue charectaristics of the material, but depends on the ability of the sliding surfaces of the

rolling elements and guide flanges or raceway to carry the load. The admissible axial load $F_{a_{max}}$ for such bearing types are as follows [10] :
Deep groove ball bearing

$$\frac{F_{a_{max}}}{C_o} < 0.50 \quad \text{if bearing bore diameter} d \leq 60 \text{ mm} \tag{2.34}$$

$$< 0.75 \quad \text{otherwise} \tag{2.35}$$

Cylindrical roller bearing(type NJ,NUP and HJ)

$$\frac{F_a}{F_r} < 0.13 \quad \text{for series 02 and 03} \tag{2.36}$$

$$< 0.20 \quad \text{for series 22 and 23} \tag{2.37}$$

Needle roller and ball assembly

$$\frac{F_a}{F_r} \leq 0.25 \tag{2.38}$$

2.4.4 Minimum Loading of Thrust Bearings

In thrust bearings, rotating at high speeds, the centrifugal foces and gyratory moments acting on the rolling elements can give rise to sliding between the rolling elements and raceways. To prevent damage, the bearing must be subjected to a minimum continuous axial load. The minimum required axial load for different bearings are as follows [10,14] :
Thrust ball and cylindrical roller thrust bearings :

$$F_a > A\left(\frac{n}{1000}\right)^2 \tag{2.39}$$

Needle roller thrust bearings :

$$F_a = \frac{C_o}{1000} \tag{2.40}$$

Spherical roller thrust bearings with combined load :

$$\frac{C_o}{1000} \leq F_a > 1.8\,F_r + A\left(\frac{n}{1000}\right)^2 \tag{2.41}$$

where F_a is minimum axial load and A is minimum load factor specified in bearing tables.
The sizes of suitable dynamically stressed bearings are derived by calculating required dynamic load rating, C_{req}, (using Equation 2.33) and then bearings having values of dynamic load rating, C, higher than the C_{req} are selected. Which are further checked for static load rating and all necesarry conditions(e.g. admissible and minimum loads etc).
Finally bearings satisfying limiting speed criteria and dimensional requirements are short-listed. Calculation procedure is shown in a system flow chart in Fig.2.3 .

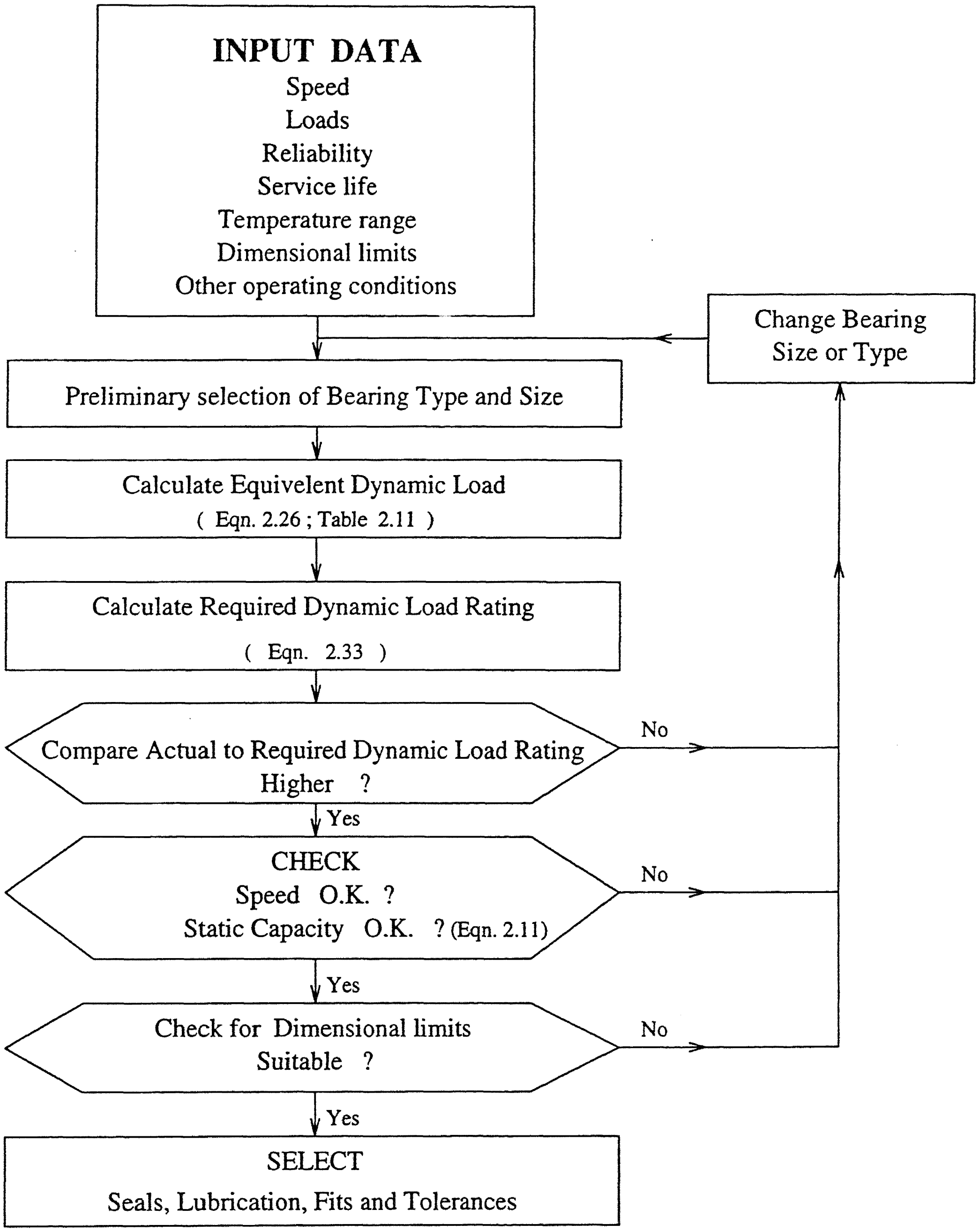


Figure 2.3: System flow chart

2.5 Selection of Lubrication Method

Rolling bearings must be lubricated to prevent metallic contact between the rolling elements, raceways and cage and also to protect from corrosion and wear. The most favourable running temperature is obtained when the minimum of lubricant, necessary to ensure reliable lubrication, is used. However, quantity also depend on sealing and cooling requirements. Lubricating properties of the lubricants deteriorate as a result of ageing and mechanical working and all lubricants become contaminated in service and therefore, must be replenished or changed from time to time.

Rolling bearings may be lubricated with grease or oil and in special cases with a solid lubricant. The choice of lubricant depends primarily on the temperature range, bearing size and operating speeds for which it is required. The summarised information regarding lubricant selection is shown in Table 2.13 .

Factor affecting the choice	*Use grease*	*Use oil*
Temperature	Up to 120°C—with special greases or short relubrication intervals up to 200/220°C	Up to bulk oil temperature of 90°C or bearing temperature of 200°C—these temperatures may be exceeded with special oils
Speed factor*	Up to *dn* factors of 300 000/350 000 (depending on design)	Up to *dn* factors of 450 000/500 000 (depending on type of bearing)
Load	Low to moderate	All loads up to maximum
Bearing design	Not for asymmetrical spherical roller thrust bearings	All types
Housing design	Relatively simple	More complex seals and feeding devices necessary
Long periods without attention	Yes, depends on operating conditions, especially temperature	No
Central oil supply for other machine elements	No—cannot transfer heat efficiently or operate hydraulic systems	Yes
Lowest torque	When properly packed can be lower than oil on which the grease is based	For lowest torques use a circulating system with scavenge pumps or oil mist
Dirty conditions	Yes—proper design prevents entry of contaminants	Yes, if circulating system with filtration

* *dn* factor (bearing bore (mm) × speed (rev/min)).

Note: for large bearings (> 65 mm bore) use nd_m (d_m is the arithmetic mean of outer diameter and bore (mm)).

Table 2.13: Selection of the lubricant [8]

2.5.1 Grease Lubrication

Generally used where bearings operate under normal conditions. Grease has certain advantages over oil like simpler housing design, less maintenance, better sealing against dirt

and moisture and less difficulty with leakage. In general, the free space in the bearing and housing should only be partly filled with grease (30–50%). Overfilling may cause overheating.

Selection

The principle factors governing the selection of grease are speed, temperature, load, bearing size and environment alongwith the properties of grease like consistency (quoted in National Lubricating Grease Institute (NLGI) scale), temperature range, load carrying ability and rust inhibiting properties. For heavily loaded bearings grease containing EP (extreme pressure) additives are used.

Relubrication Interval

The period during which a graese lubricated bearing will function satisfactorily without relubrication is dependent on the bearing type, size, speed, operating temperature and the grease used. The relubrication interval (hours of operation) may either be obtained from the chart shown in Fig. 2.4 or calculated by following expression [9] :

$$t_f = k\left(\frac{14 \cdot 10^6}{n \cdot \sqrt{d}} - 4\,d\right) \tag{2.42}$$

where :
t_f = service life of grease or relubrication interval in hours
k = factor, depend on type of bearing

Amount of Grease

The required amount of grease may be calculated from expression [9] :

$$G = 0.005 \cdot D \cdot B \qquad \text{[grams]} \tag{2.43}$$

where :
G = weight of grease, gm
D, B = outside diameter and width of bearing, mm

2.5.2 Oil Lubrication

Oil lubrication is generally used when,

1. High speed and temperature prohibit the use of grease,
2. It is necessary to transfer frictional or applied heat away from bearing,
3. Adjecent machine parts are oil lubricated.

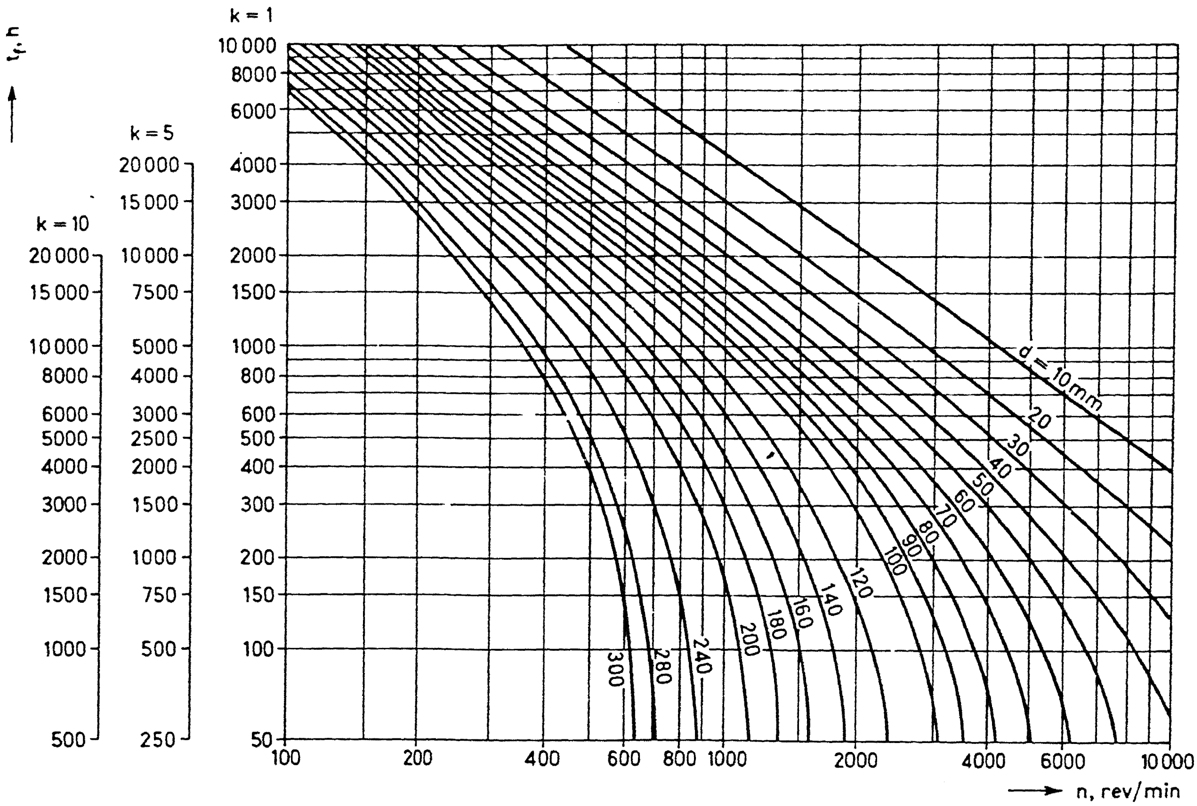


Figure 2.4: Relubrication interval [9]

Only solvent refined mineral oils with high or medium viscosity index (HVI or MVI) are generally used. Oils containing additives are normally required for exceptional operating conditions e.g. appreciable sliding in case of taper or spherical roller bearings, operating under heavy or shock load etc.

Selection

Viscosity is the most important criteria for selection of lubricant oil. In order to ensure a sufficient thick film of oil to be formed in the contact area, the oil must retain a minimum viscosity at the operating temperature (see Table 2.14). The suitable oil viscosity can be selected by considering the bearing size, speed and operating temperature from the nomogram shown in Fig.2.5. In nomogram, initially for the given speed (n), bearing bore diameter (d) and operating temperature (T), the required viscosity ν_1 is obtained. Since the viscosity varies with temperature and lubricating oils are commercially available with

viscosities specified at a particular temperature (say $50^{\circ}C$), finally the required viscosity ν at that temperature ($50^{\circ}C$) is selected.

Bearing application	Operating temperature °C	Bearing application	Operating temperature °C
Cutter shaft of planing machine	40	Face grinding machine	55
Bench drill spindle	40	Jaw crusher	60
Horizontal boring spindle	40	Axleboxes of locomotives and passenger coaches	60
Circular saw shaft	40	Hammer mill	60
Blooming and slabbing mill	45	Wire mill	65
Lathe spindle	50	Vibratory motor	70
Vertical turret lathe	50	Rope stranding machine	70
Double-crank saw frame	50	Vibrating screen	80
Wood cutter spindle	50	Impact mill	80
Calender roll of a paper making machine	55	Ship's propeller thrust block	80
Backup rolls of hot strip mills	55	Vibrating road roller	90

Table 2.14: Operating temperatures of bearings in different machines [14]

However, it is very difficult to estimate required oil viscosity for a bearing application through computer programs or mathematical calculations by using nomogram and moreover no mathematical model or any method other than the nomogram is available in the literature so far. In nomogram the values are experience based and all scales used are neither linear nor interrelated logically, making it further difficult to develop any mathematical model. For this a mathematical model is developed and various steps involved in developement and, results compared with the values obtained from nomogram are described in the following section

1. For every constant value of speed (n) [rev/min] the relation between bearing bore diameter (d) and required viscosity ν_1 at operating temperature (T) were analysed and among all mathematical forms, the following equations using power law were found best suitable.

$$\begin{aligned}
\nu_1 &= (d)^{-0.426728} \cdot 225.502 && \text{for } n = 300 \\
&= (d)^{-0.359295} \cdot 108.938 && \text{for } n = 500 \\
&= (d)^{-0.324920} \cdot 60.6023 && \text{for } n = 1000 \\
&= (d)^{-0.290315} \cdot 41.4877 && \text{for } n = 1500 \\
&= (d)^{-0.286292} \cdot 28.6498 && \text{for } n = 3000
\end{aligned} \tag{2.44}$$

2. All above equations are represented by a general equation :

$$\nu_1 = d^{-\eta_1} \cdot \zeta_1 \tag{2.45}$$

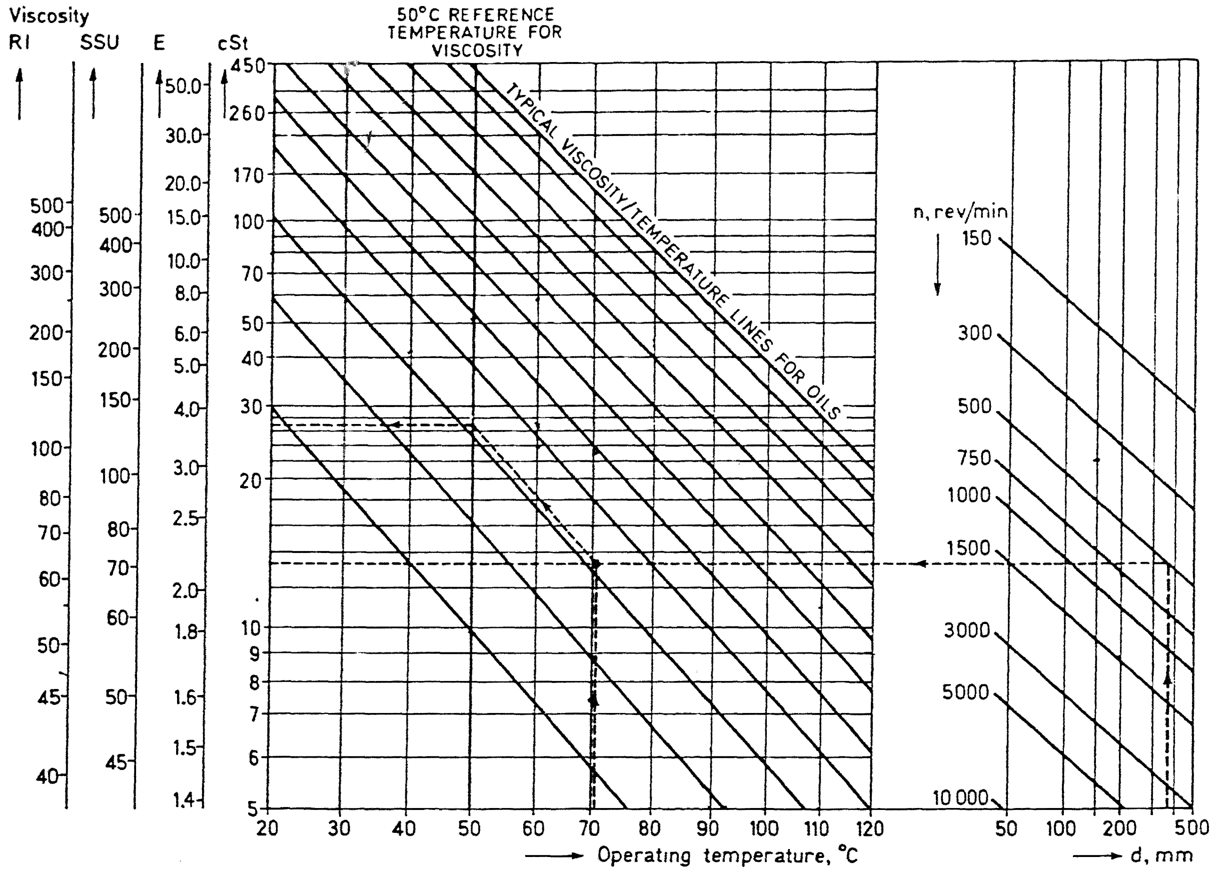


Figure 2.5: Nomogram to select oil viscosity [8]

where, ζ_1 and η_1 are the constants for a perticular RPM value (n). Relation between RPM values and constants ζ_1 and η_1 were found and are as follows :

$$\zeta_1 = (n)^{-0.888114} \cdot 30448 \tag{2.46}$$
$$\eta_1 = (n)^{-0.174964} \cdot 1.10223 \tag{2.47}$$

3. For every constant value of ν_1 , the relation between required viscosity ν at $50\,^{\circ}C$ and operating temperature, T , were analysed and the general equation representing all the equations found suitable using exponential form is as follows :

$$\nu = \Phi \cdot \exp^{(\eta_2 \cdot T)} \cdot \zeta_2 \tag{2.48}$$

where, ζ_2 and η_2 are constants for a particular value of ν_1 (Table 2.15) and Φ is a modification factor to take into account the variation in viscosilty requirements in different RPM

ranges. Its values are as follows :

$$\begin{aligned}\Phi &= 1.30 && \text{for } n \leq 200 \\ &= 1.13 && \text{for } 200 < n \leq 350 \\ &= 1.00 && \text{for } n > 350 \end{aligned} \tag{2.49}$$

4. Relations between ν_1 and constants ζ_2 and η_2 were found and are as follows :

ν_1 (cst)	η_2	ζ_2
6	0.030953	1.25114
8	0.033160	1.49269
10	0.035621	1.6304
20	0.043424	2.1595
40	0.048751	3.40775
70	0.051191	5.53141

Table 2.15: Values of constants ζ_2 and η_2

$$\zeta_2 = 0.008737 \cdot \ln(\nu_1) + 0.015520 \tag{2.50}$$
$$\eta_2 = 0.065234 \cdot \nu_1 + 0.904462 \tag{2.51}$$

The procedure to be used to calculate the required viscosity ν is as follows :

- Calculate constants ζ_1 and η_1 for given speed(n) using equations 2.46 and 2.47 .
- Calculate ν_1 for given bearing bore diameter d from equation 2.45 .
- Calculate constants ζ_2 and η_2 for obtained value of (ν_1) using equations 2.50 and 2.51.
- Finally calculate ν for given operating temperature T from equation 2.48.

The results obtained for different values of speed, bore diameter and operating temperature are compared with nomogram values and found quite in agreement (shown in Table 2.16).

2.6 Selection of Shaft and Housing Fits and Tolerances

To prevent the damage of the bearings and associated components it is important to maintain correct fits between the bearings and seatings. The most important factors which are considered while selecting bearing fits are as follows :

Speed	Bore dia.	Oper. temp.	Viscosity (cst)			
			Calculated		Nomogram	
(n)	(d)	(T)	(ν_1)	(ν)	(ν_1)	(ν)
150	50	50	76.83	76.83	80	80
150	100	60	55.91	87.91	58	90
150	200	80	40.68	147.1	41	170
300	50	80	44.29	175.87	44	180
300	200	70	25.22	52.81	24.5	53
300	500	120	17.38	243.72	17	255
500	100	50	22.05	22.05	21	21
500	150	70	18.97	38.93	18	38
750	200	90	13.61	56.42	13.2	57
1000	50	60	18.20	24.29	17.5	25
1000	150	50	12.68	12.68	12.2	12.2
1000	300	90	10.09	38.89	11	42
1500	100	110	11.21	92.03	11	90
3000	100	70	7.12	13.47	7.4	13.8
5000	150	80	4.55	11.91	5.0	11

Table 2.16: Comparison of calculated and nomogram values of ν and ν_1

Conditions of rotation : It refers to direction of load in relation to the bearing rings. In case of rotating load (load moving relative to the bearing ring) an interference fit is used to prevent creep of load on its seating causing wear (fretting corrosion) of the contacting surfaces whereas, in case of stationary load (load is stationary relative to the ring) an interference fit is not necessary unless dictated by other requirements. When the direction of the load is indeterminate, it is desirable that both rings have interference fit.

Magnitude of load : The load on bearing inner ring cuases it to expand resulting in an easing of fit on the seating hence heavier the load, the greater is the interference required.

Displacement of a non locating bearing : When a non-separable bearing is used at the non-locating position, it is necessary that under all conditions of operation one of the rings is free to move axially and is ensured by using a clearance fit.

Other factors : In addition to factors mentioned above, internal clearance, temparature conditions, requirements regarding running accuracy, design and material of shaft and housing and ease of mounting and dismounting are also considered. The summarised information for selection of shaft and housing fits is shown in Tables 2.17 to 2.21 . According to the type of fit the bearing bore and outside diameter tolerances alongwith shaft diameter and housing bore tolerances are obtained from standard tolerance tables(ISO :BS 4500).

Design and Operating Conditions		Ball Bearings				Cylindrical Roller Bearings				Spherical Roller Bearings				Tolerance Classification
		Basic Bearing Bore												
		mm		in.		mm		in.		mm		in.		
Rotational Conditions	Radial Loading	Over	Incl.	Over	Incl.	Over	Incl.	Over	Incl.	Over	Incl.	Over	Incl.	
Inner ring rotating in relation to load direction	Light radial load	0	18	0	0.71									h5
		18	All	0.71	All	0	40	0	1.57	0	40	0	1.57	j6[c]
						40	140	1.57	5.52	40	100	1.57	3.94	k6[c]
						140	320	5.52	12.6	100	200	3.94	7.88	m6[c]
	Normal radial load	0	18	0	0.71									j5
		18	All	0.71	All	0	40	0	1.57	0	40	0	1.97	k5
						40	100	1.57	3.94	40	65	1.57	2.56	m5
						100	140	3.94	5.52	65	100	2.56	3.94	m6
						140	320	5.52	12.6	100	140	3.94	5.52	n6
										140	280	5.52	11.1	p6
										280	500	11.1	19.7	r6
or										500	All	19.7	All	r7
Load direction is indeterminate	Heavy radial load	18	100	0.71	3.94									k5
		100	All	3.94	All	0	40	0	1.57	0	40	0	1.57	m5
						40	65	1.57	2.56	40	65	1.57	2.56	m6
						65	140	2.56	5.52	65	100	2.56	3.94	n6
						140	320	5.52	12.6	100	140	3.94	5.52	p6
										140	200	5.52	7.88	r6
										200	All	7.88	All	r7
Inner ring stationary in relation to load direction	All loads: Inner ring must be easily axially displaceable	All sizes												g6
	All loads: Inner ring need not be easily axially displaceable	All sizes												h6
Pure thrust (axial) load		All sizes												j6

Table 2.17: Fits for shafts for radial bearings [15]

Thrust bearings **Shaft**

Type of load	**Bearing type**	**Shaft diameter**	**Operating conditions**	**Tolerance field**
Axial load	Thrust ball bearings	All sizes		j6
	Thrust ball bearings double-acting	All sizes		k6
	Cylindrical roller thrust bearings or thrust needle roller and cage assemblies with shaft washer	All sizes		h6 (j6)
	Thrust cylindrical roller and cage assemblies or thrust needle roller and cage assemblies with track or thrust washer	All sizes		h10
	Thrust cylindrical roller and cage assemblies or thrust needle roller and cage assemblies	All sizes		h8
Combined load	Spherical roller thrust bearings	All sizes	Point load on shaft washer	j6
		up to 200 mm	Circumferential load on shaft washer	j6 (k6)
		over 200 mm		k6 (m6)

Table 2.18: Fits for shafts for thrust bearings [14]

<table>
<tr><th colspan="4">Design and Operating Conditions</th><th rowspan="2">Tolerance Classification</th></tr>
<tr><th>Rotational Conditions</th><th>Loading</th><th>Outer Ring Axial Displacement Limitations</th><th>Other Conditions</th></tr>
<tr><td rowspan="4">Outer ring stationary in relation to load direction</td><td rowspan="3">Light, normal, and heavy</td><td rowspan="3">Outer ring must be easily axially displaceable</td><td>Heat input through shaft</td><td>G7</td></tr>
<tr><td>Housing split axially</td><td>H7</td></tr>
<tr><td>Housing not split axially</td><td>H6[c]</td></tr>
<tr><td>Shock with temporary complete unloading</td><td rowspan="7">Outer ring need not be axially displaceable</td><td rowspan="2"></td><td rowspan="2">J6[c]</td></tr>
<tr><td rowspan="3">Load direction is indeterminate</td><td>Light and normal</td></tr>
<tr><td>Normal and heavy</td><td rowspan="4">Split housing not recommended</td><td>K6[c]</td></tr>
<tr><td>Heavy shock</td><td rowspan="2">M6[c]</td></tr>
<tr><td rowspan="3">Outer ring rotating in relation to load direction</td><td>Light</td></tr>
<tr><td>Normal and heavy</td><td>N6[c]</td></tr>
<tr><td>Heavy</td><td>Thin wall housing not split</td><td>P6[c]</td></tr>
</table>

Table 2.19: Fits for housings for radial bearings [15]

Thrust bearings			Housing
Type of load	**Bearing type**	**Operating conditions**	**Tolerance field**
Axial load	Thrust ball bearings	Standard running accuracy	E8
		High running accuracy	H6
	Cylindrical roller thrust bearings or thrust needle roller and cage assemblies with housing washer		H7 (K7)
	Thrust cylinder roller and cage assemblies or thrust needle roller and cage assemblies with track or thrust washer		H11
	Thrust cylindrical roller and cage assemblies or thrust needle roller and cage assemblies		H10
	Spherical roller thrust bearings	Normal load	E8
		High load	G7
Combined load point on housing washer	Spherical roller thrust bearings		H7
Combined load circumferential load on housing washer	Spherical roller thrust bearings		K7

Table 2.20: Fits for housings for thrust bearings [14]

2.7 Selection of Sealing Methods

Bearings must be protected by suitable seals against the entry of moisture, dirt and other contaminants and to prevent the loss of lubricant. Many factors are considered when deciding the best sealing arrangement for a given bearing application e.g. type of lubricant, peripheral speed at the sealing surface, misalignment of the shaft, available space, friction, temperature rise and cost. Bearings having integral seals or shields may also be used for saving space.

Seal Type	Suitability									
	Lubrication		Speed	Tempe-rature	Dirt	Mois-ture	Insta-llation	Cost	Space Reqd.	Specific Charecteristics
	oil	grease								
Non Rubbing seals										
Simple gap	No	Yes	High	High	No	No	Easy	Low	Mod.	
grooved Labyrinth	No	Yes	High	High	Low	Low	Mod.	Mod.	Mod.	
Labyrinth with spiral groove	Yes	Yes	High	High	Low	Low	Mod.	High	Mod.	For horizontal shafts
Labyrinth with Radial Webs	No	Yes	High	High	Mod.	Low	Mod.	Mod.	Mod.	For split housing
Labyrinth with Axial Webs	No	Yes	High	High	Mod.	Low	Mod.	Mod.	Mod.	For solid housing
Labyrinth with Inclined Webs	No	Yes	High	High	Mod.	Low	Mod.	Mod.	Mod.	Self aligning bear.
ready to mount Labyrinth unit	No	Yes	High	High	Mod.	Low	Easy	Mod.	Mod.	
Labyrinth with Piston rings	Yes	Yes	High	High	Mod.	Low	Mod.	Mod.	Low	
Oil groove rings	Yes	Yes	High	High	Mod.	Low	Mod.	Mod.	Mod.	For horizontal shafts
Flinger rings	Yes	No	High	High	Mod.	Low	Mod.	Mod.	Mod.	
Rubbing seals										
Felt	No	Yes	Low	Low	Mod.	Low	Mod.	Low	Mod.	
Asbestos graphite	No	Yes	Low	Mod.	Mod.	Mod.	Mod.	Mod.	Mod.	
lip	Yes	Yes	Low	Mod.	Mod.	Mod.	Mod.	Mod.	Mod.	
V ring	Yes	Yes	Mod.	High	Mod.	High	Easy	Mod.	Mod.	
Spring steel seals	No	Yes	High	High	Mod.	High	Mod.	Mod.	Mod.	Deep groove ball bear.
Combined seals	Yes	Yes	High	High	High	High	Mod.	High	High	

Table 2.21: Seals for different bearing applications [10,14]

Chapter 3

System Design and Implementation

The present chapter describes the design and implementation of the proposed bearing selection system named **BEARSEL**. After requesting for the minimum essential input data from the user, BEARSEL is capable of selecting the best fit bearing for a specific problem and also advising the user on the installation (lubrication, sealing etc) of the bearing. To make the system responsive to dynamic information, the facility of updating database has been incorporated. Further, in addition to displaying inputs and outputs on the screen at various stages of the system run, on line printing option is included to get hardcopies. The expense on the stack memory is compensated by the near 100 % menu contact with the user.

The system is interactive, menu driven and user friendly. It is implemented using DBase IV.2 on an IBM compatible PC-XT/AT.

3.1 Menu Structure

Based on the system flow chart (Fig. 2.3), BEARSEL is designed and implemented in six modules as follows :

- Data-Input/Edit
- Bearing Selection
- Installation of Bearings
- Update
- Print
- Exit

It is presented by a menu structure shown in Fig.3.1. Each option of the top horizontal (main) menu refers to one module, which further leads to sub-menus and sub-sub-menus. Menus which appear in sequence depend on previous selections. Only relevent alternatives

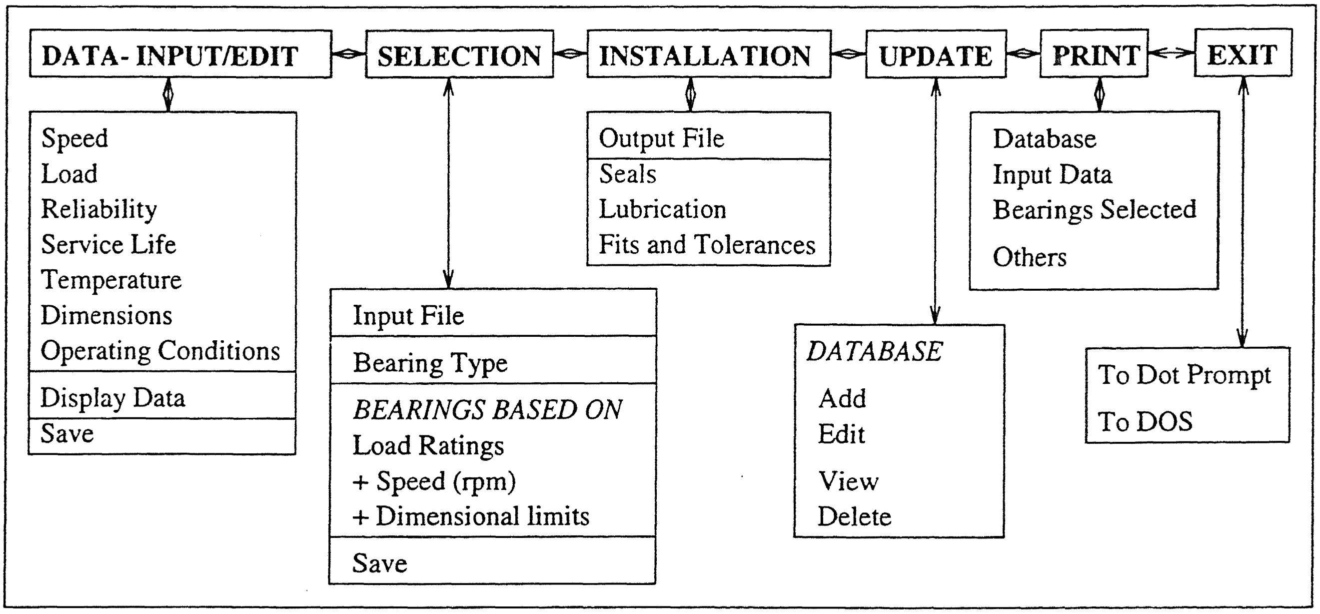


Figure 3.1: Menu structure of the BEARSEL

are presented in each new menu. The hierarchical and chain, hybrid menu structures can be easily traversed with the help of cursor keys and selection of option is made by pressing return key. Although all the modules are interlinked and users have easy access to any menu or sub-menu option from any current position, a certain order is necessary to be followed while inputting data or selecting bearings. Screen printouts for all modules are shown in Appendix A.

3.2 Input to the System (DATA-INPUT/EDIT)

This is the initial and independent module with which the user interacts to give necessary inputs. The remaining modules are dependent upon the knowledge base and inputs acquired by this module. The system provides various alternatives for each type of input from which the user is expected to select and enter the data in both qualitative as well as quantitative forms. Essentially, all the input information should be entered to get good results from the system. The flow chart of implementation procedure for this module is shown in Fig 3.4. The various inputs required with the order in which they are to be entered are as follows:

3.2.1 Speed

The system displays two options, **Constant** and **Variable** to enter speed data. For constant speed, user has to enter speed value (rpm) whereas, in case of variable, number of steps of speed cycle, speed values and peccentage of cycle/total time for all steps are to be entered. Mean speed is then calculated by the system (Eqn. 2.27).

3.2.2 Load

The load data are entered by selection from a series of menus which is implemented as follows :

1. Selection of load type (Radial, Thrust and Sudden) one by one.

2. Selection of magnitude (Negligible, Constant or Variable) for radial and thrust load types followed by selection of nature (Step, Fluctuating, Stationary cum Rotary or Other forms), if magnitude is variable.

   For sudden load selection is done from type of shock (Negligible, Light, Medium or Heavy). System provides help to the user in selection by displaying type of shock for various applications (Table 2.12).

3. Enter values of required load parameters depending on type, magnitude and nature of load (see Table 3.1).

4. Selection of load direction (Constant, Rotating or Indeterminate for radial load, and Single or Double acting for thrust load).

5. Calculation of Mean loads for radial and thrust load types (if magnitude is variable) and shock factor FS. References of equations and tables involved are mentioned in Table 3.1.

6. Finally return to main input menu with Exit option

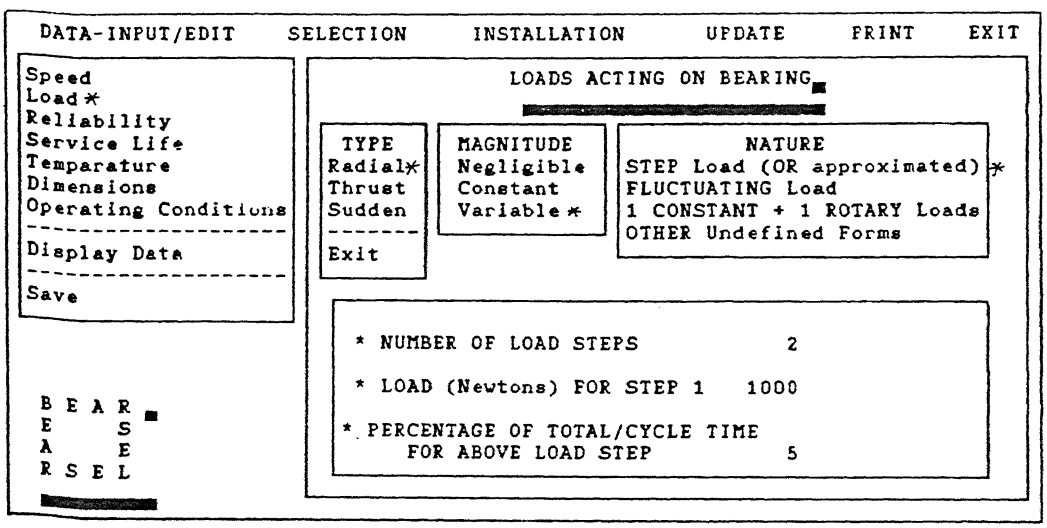
A screen printout is shown in Fig. 3.2 which shows how load data are entered. The user has selected the * marked choices for a variable radial load of step nature and has entered appropriate values.

3.2.3 Reliability

Here, user is asked to enter reliability if desired more than 90 % (Range 90–99 %). System then calculates life adjustment factor, a_1 (Table 2.7).

Load			System action
Type	Magnitude /Nature	Required Parameters	
Radial and Thrust	Negligible	—	Return
	Constant	Load value, Direction	Store value
	Variable	load direction +	Calculate mean load; Store values
	Step	(# of steps; load values; % of cycle/total time)	(Eqn. 2.28) for const. speed (Eqn. 2.29) for var. speed
	Fluctuating	(max. and min. load values)	(Eqn. 2.30)
	Stationary-cum Rotary	(constant load value; rotating load value)	(Eqn. 2.31)
	Other Forms	mean load value	Store value
Sudden	Negligible	—	Calculate shock Factor (FS) (Table 2.12)
	Light Shock	—	
	Med. Shock	—	
	Heavy Shock	—	

Table 3.1: Implementation details of Load Input Data



Enter the % of cycle/total time for this load step

Figure 3.2: Screen printout of Load Input

3.2.4 Service Life

For the convinience of the user, system provides two alternatives to enter bearing service life (Requisite basic rating life) data.

1. For general bearing applications requisite life may be entered in terms of operating hours.

2. For rail/road applications life data may be entered in millions of kilometers with wheel diamter in meters.

Help is provided to assist the user in determining requisite life for various applications (Tables 2.8 and 2.9)

3.2.5 Temperature

Here, expected maximum and minimum bearing temperature in ^oC are to be entered. Depending on maximum temperature system calculates temperature factor FT (Table 2.10).

3.2.6 Dimensions

Dimensional constraints to be satisfied by the bearing are to be entered in terms of maximum and minimum bearing bore diameter, outer diameter and width in mm.

3.2.7 Operating Conditions

A special care is required while inputing operating conditions. Several operating conditions are displayed (shown in Fig.3.3) and user has to select desired level for each of them from the following options :

- Critical
- Important
- Usual
- Undesirable

Depending on desired level selected. each of the operating conditions is assigned a weighted factor which is used to identify suitable bearing types and then grading (ranking) them. The option 'critical' should only be selected when it is extremely demanding by the application because otherwise the system will eliminate all those bearing types which are not critically suitable for that operating condition. For example, running quietness is critical for the bearings of electric motors used in hospitals, offices or homes but not for those, used in industries.

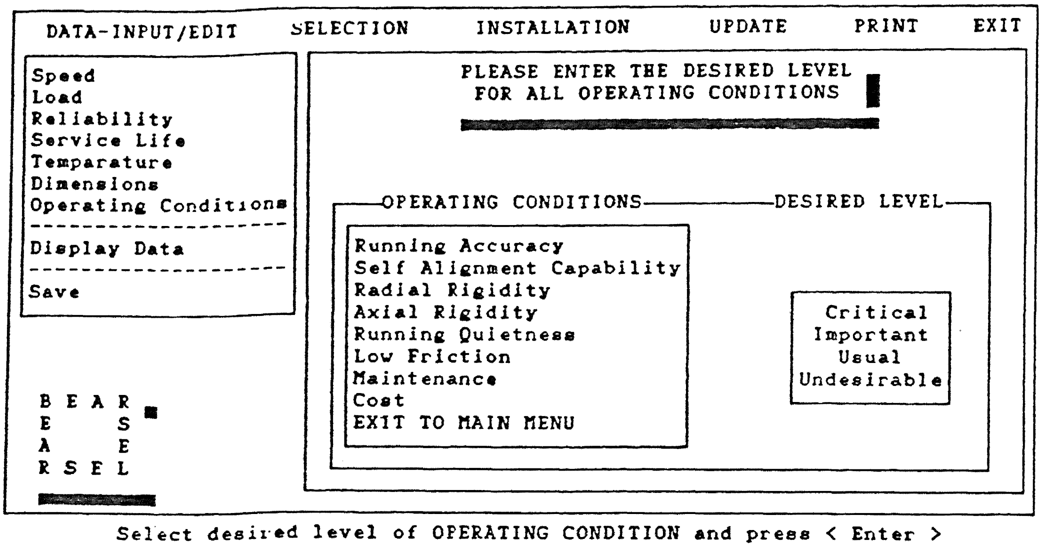


Figure 3.3: Screen printout of Operating Conditions Input

In addition to these inputs, **Display Data** and **Save** options have also been provided to facilitate the user to view and check the inputs and then save them for future requirements.

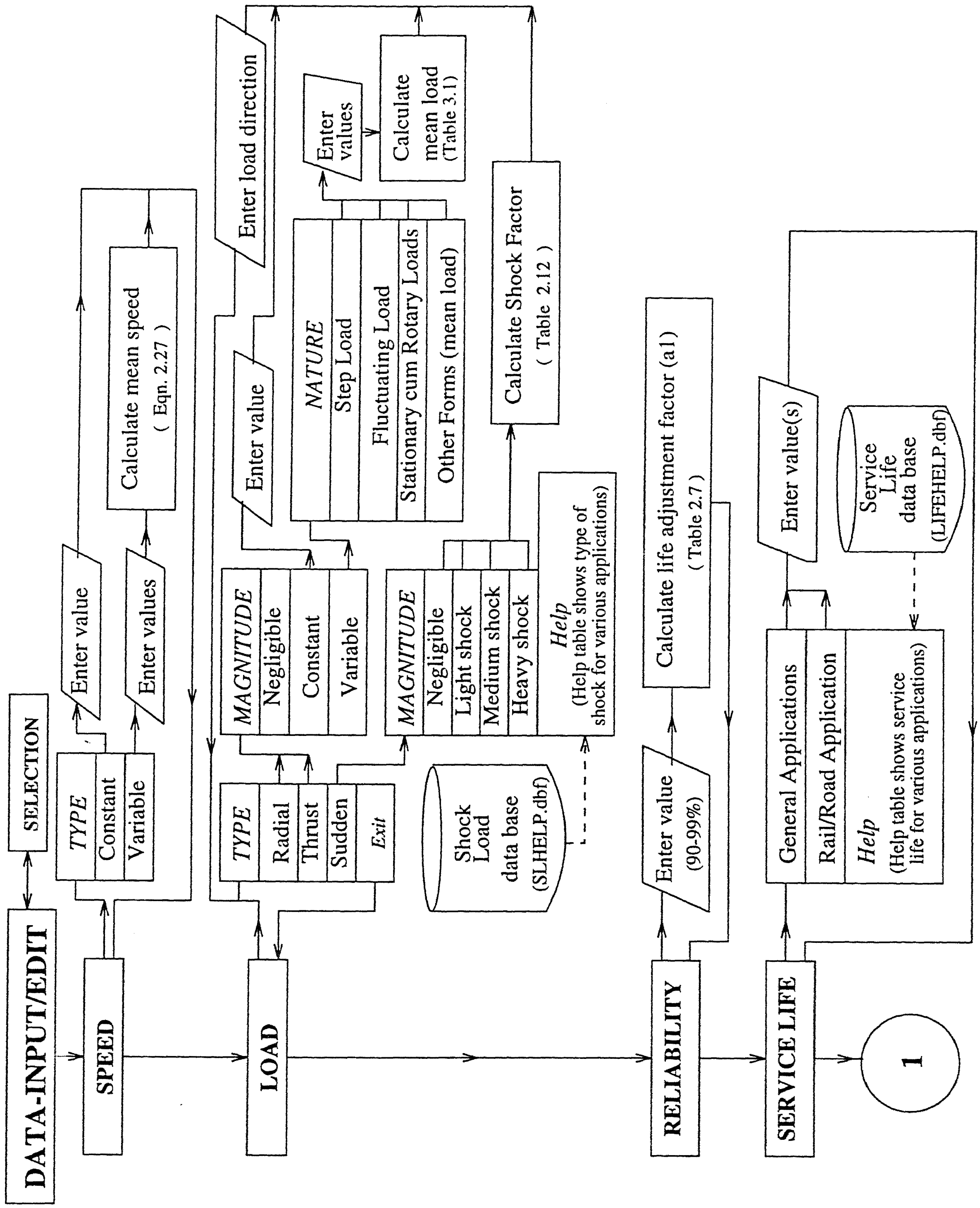


Figure 3.4: Flow chart: Implementation Procedure of DATA-INPUT/EDIT module

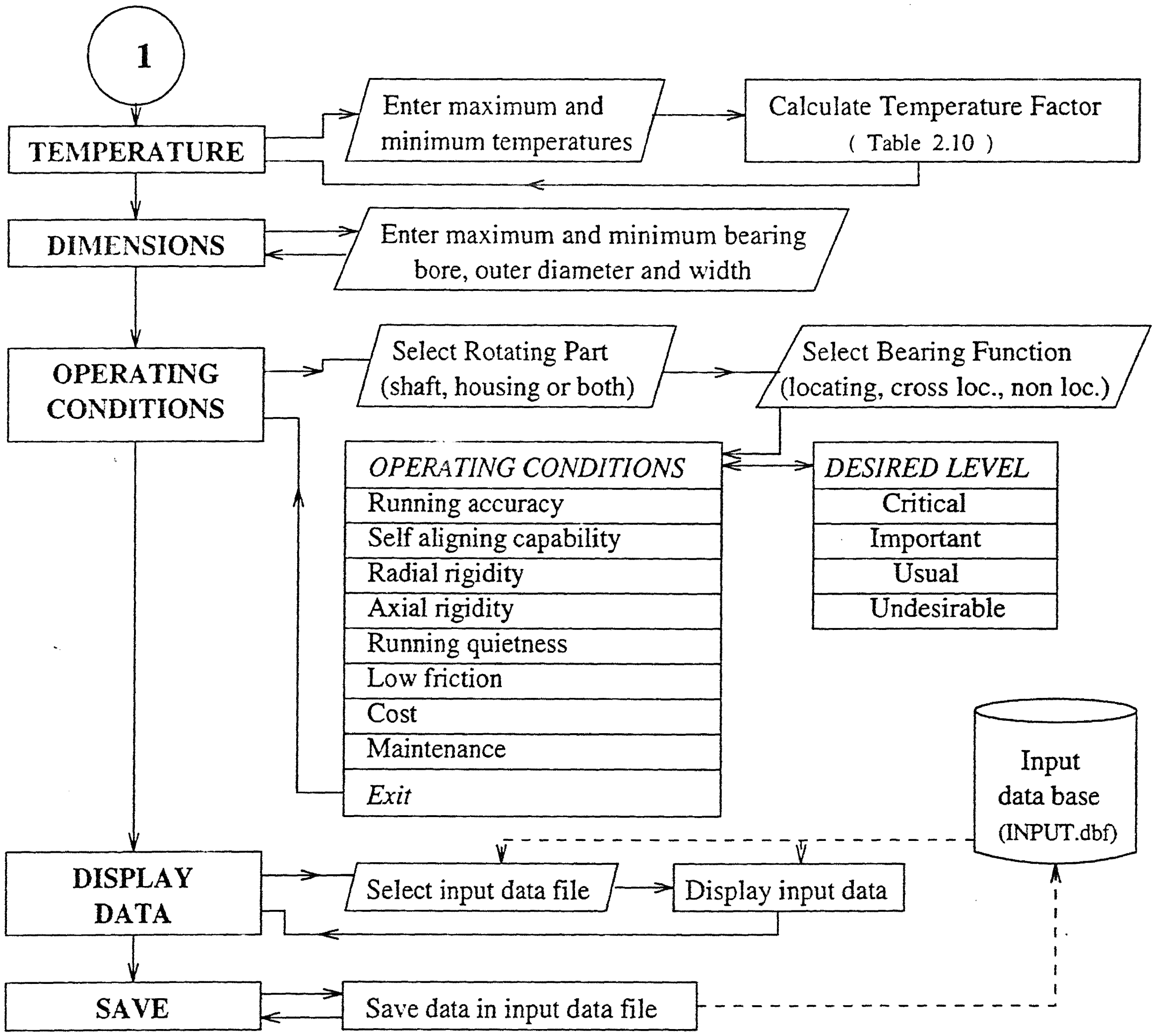


Figure 3.4: (contd ...)

3.3 Selection of Bearings (SELECTION)

It is a decision making module of BEARSEL, and may be called as the "crux" of the system. First of all the user has to select the input file to retrieve relevent application (input) data, acquired in data input module, for which bearings are to be selected. Based on input and charecteristics of various bearing types (discussed in Section 2.3), this module identifies and ranks the suitable bearing types which are displayed for the user in the order of preference. Out of the displayed alternatives, the user has to select one depending upon the preference, economic considerations, availability and design constraints. Finally the system selects the bearings of appropriate size by pruning of alternatives (bearings) available within that bearing type. Selected bearings are then displayed for the user and saved in an output file for future use. The flow chart of implementation procedure is shown in Fig. 3.7 .

3.3.1 Selection of Bearing Types

Here the system works exactly in the same manner as an expert does. It first lists all the possible bearing types using a knowledge-base and a set of rules which describe the suitability, unsuitability and relative suitability of all bearing types for each of the design attributes, operating conditions and relevent parameters (Tables 2.1–2.4). Then by elimination process it tests the suitability of all possible alternatives for the pertinent attributes and operating conditions (specified for that application), one at a time, to eliminate unsuitable bearing types. For example, if the required bearing function is "Locating" then bearing types as, cylindrical roller bearings (type N, NU) and bearings having filling slots can not be used, which are then eliminated from the list of suitable candidates. It is implemented as follows :

1. Sorting of bearing types based on maximum speed available with that bearing type (Table 2.1).

2. Sorting of bearing types based on loading conditions.(Depending on whether, bearing is to carry only radial load, only thrust load or combined load, bearing types capable of carrying that load are sorted (see Table 2.1)). Further depending on particular loading condition, sorting is done based on,

   - Admissible load ratio F_a/F_r for combined loads (Table 2.1).
   - Thrust load direction for only thrust load (capability of bearing type to carry thrust load in single or double direction is checked)(Table 2.1)
   - Bearing function for only radial and combined loads (locating capability is checked)(Table 2.1).

3. One by one Sorting of bearing types based on desired level for each of the operating conditions (Table 2.3). Here, for any critical operating condition, the bearing types not having excellent or good suitability are eliminated from the list of possible candidates.

3.3.2 Ranking of Suitable Bearing Types

After identification of certain suitable types of bearing, the evaluation of the relative suitability of these bearing types is carried out by grading (ranking) them on the basis of weighted factor method. The procedure adopted is as follows :

- All bearing types have different degree of capability and suitability (Tables 2.1 and 2.3) relative to each other for a particular attribute (load carrying ability, locating ability etc.) or operating condition. Depending on degree of suitability/capability each bearing type is assigned a numeric value as follows:

Degree of suitability/capability	Value
Excellent	4
Good	3
Fair	2
Poor	1
Unsuitable	0

- A suitability matrix is generated whose rows are represented by suitable bearing types and columns by pertinent attributes (radial load capacity in case of when only radial load is acting etc.) and operating conditions. Each element of matrix represents relative suitability of corresponding bearing type (row) with respect to that perticular attribute/operating condition (column).

- Based on input data, weighted factors for each of the attribute and operating condition are determined. For example, an operating condition having critical or important as desired level, is assigned higher weighted factor (priority) than to a condition having usual as desired level.

- Now, columns of suitability matrix are multiplied by corresponding weighted factors to introduce the relative priority of different attributes and operating conditions for that particular application.

- Finally elements of each row of suitability matrix are summed up. The resulting value (weighted value) for each bearing type indicates the relative suitability for the entered inputs. Higher is the weighted value, higher is the preference. The selected bearing types in order of preference are then displayed and stored with input data in a temporary database.

The Fig.3.5 shows a screen printout of selected bearing types in the order of preference.

3.3.3 Selection of Optimum Sized Bearings

Initially the user is asked to select one bearing type out of the sorted list of suitable bearing types (based on preference, cost, availability and other factors). Accordingly the

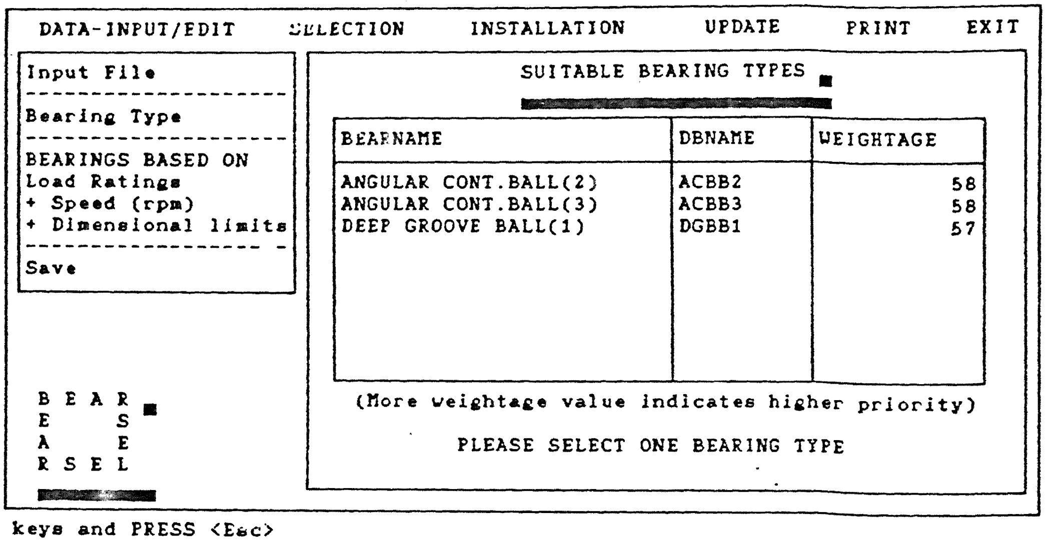


Figure 3.5: Screen printout of suitable bearing types

system retrieves the relevent bearing database and input data. For all bearing types, separate databases have been generated which store the relevent information and values of pertinent attributes (boundary dimensions, basic load ratings, limiting speeds, load factors, mass etc.) of all bearings which are available from different manufacturers.
The final selection is achieved in three stages as follows :

Selection of Bearings based on Load Ratings

Initially using input data and data available in bearing database (of selected bearing type), for each bearing, equivalent dynamic load, P, and equivalent static load, P_o, are calculated (Equations 2,26 and 2.11; Tables 2.5 and 2.11). Then required dynamic load rating, C_{req}, is calculated (Eqn. 2.33) and compared with basic dynamic load rating, C (specified for each bearing in bearing database). If C is found greater than to C_{req}, the bearing is further checked for safe index of static stressing (Eqn. 2.12; Table 2.6) and is stored in a temporary database, otherwise it is dropped (not copied to temporary database of suitable bearings). Same process continues until whole database is not scanned. Sorted data (selected bearings based on load ratings) are then displayed for the user. If no bearing is found suitable at any stage, user is suggested to select another bearing type.

Selection of Bearings based on Limiting Speed (RPM)

Here the bearing data base, which has already been sorted for load ratings, is further scanned to sort the bearings satisfying the condition of required speed (input data) is lower than limiting speeds (specified in bearing database for each bearing). All suitable

bearings are displayed and stored into a temporary database.

Selection of Bearings based on Dimensional Constraints

Sorted database obtained from previous stage is further scanned and sorted for bearings satisfying dimensional constraints (maximum and minimum bearing, bore diameter, outer diameter and width). Finally selected bearings are then displayed for the user and are saved in an output database.

The screen printout of the finally selected bearings is shown in Fig.3.6 and flow chart of implementation procedure for this module is shown in Fig. 3.7.

FINALLY SELECTED SUITABLE BEARINGS

B_NUMBER	COMPANY	BORE_DIA	OUTER_DIA	WIDTH	C	CO	RPM_OIL	RPM_GRES	M
7314BG	SKF	70	150	70	143000	143000	3800	2800	
7315BG	SKF	75	160	74	153000	160000	3600	2600	
7316BG	SKF	80	170	78	166000	180000	3400	2400	

B_NUMBER : Bearing Number
C : Dynamic Load Rating(Newtons)
CO : Static Load Rating(Newtons)
RPM_* : Limiting Speeds(rpm)
MASS : Weight of bearing(g)
Linear Dimensions are in m.m.

PRESS [ESC] TO CONTINUE FURTHER
Use keys to see all BEARINGS and SPECIFICATIONS

Figure 3.6: Screen printout of finally selected bearings

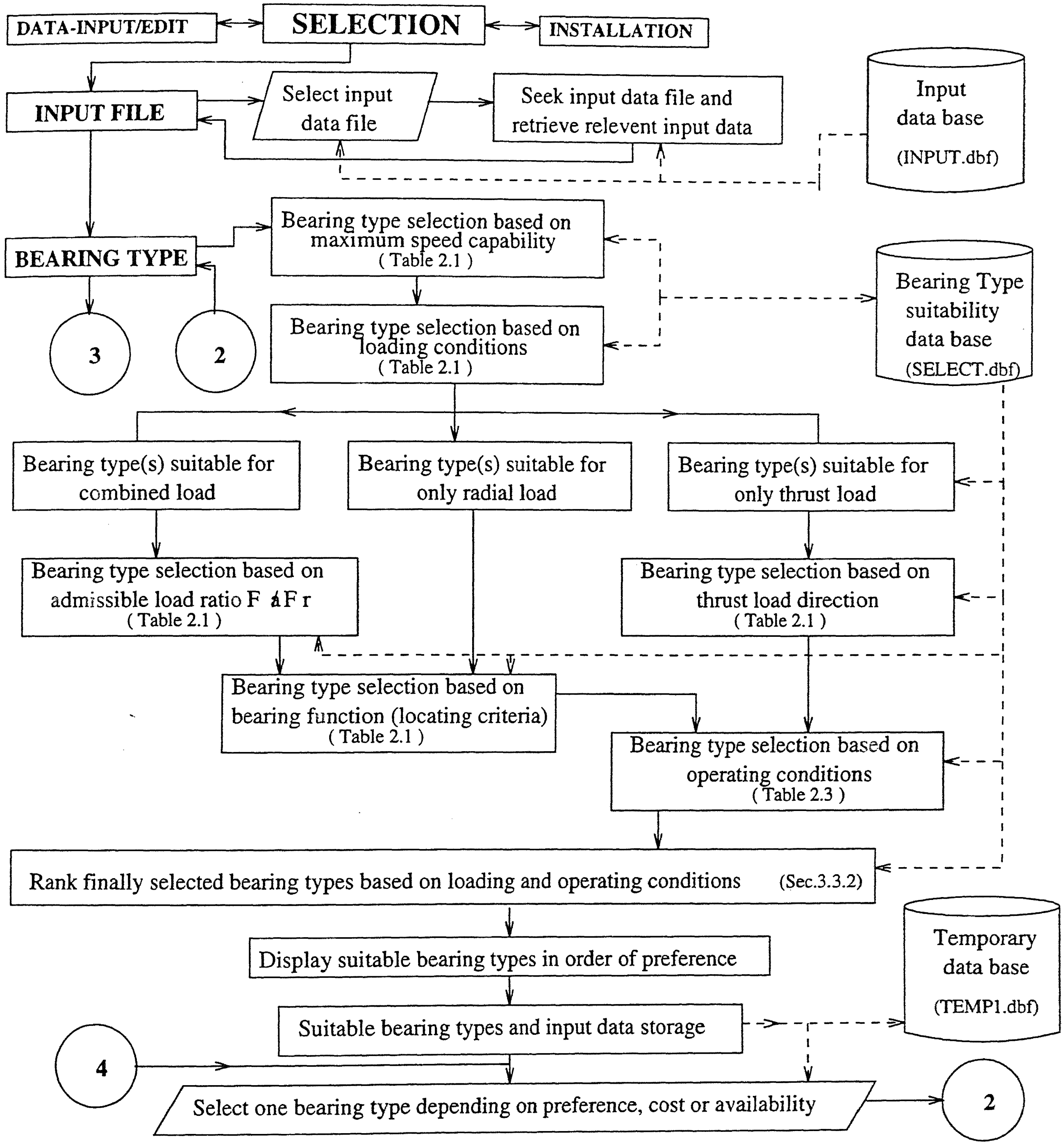


Figure 3.7: Flow chart: Implementation Procedure of SELECTION module

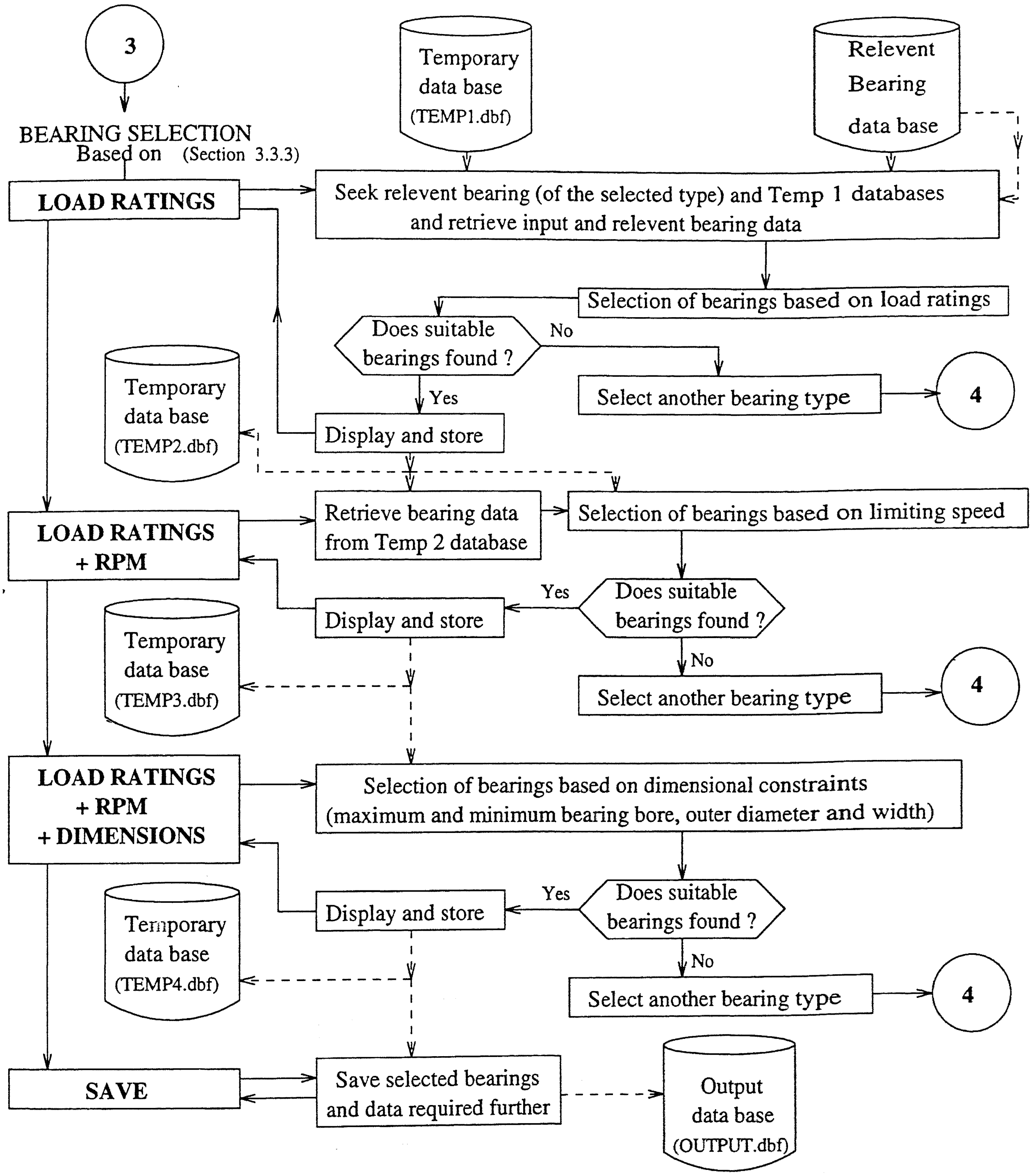


Figure 3.7: (contd ...)

3.4 Installation of Bearings (INSTALLATION)

In this module three major application areas of the bearing installation have been included about which the user is given advice. These are :

- Seals,
- Lubrication, and
- Fits and tolerances.

Initially the user is asked to select the output file (in which finally selected bearings have been saved), accordinly the system retrieves the relevent selected bearings with required data. Then user has to select one bearing for which advice on installation is seeked. Recommendations are displayed for the application area (seals, lubrication etc.), selected by the user. The flow chart of implementation procedure is shown in Fig. 3.11 .

3.4.1 Selection of Sealing method

The database of selected bearing is scanned to check the availability of bearing with integral seals or shields (specified for each bearing in bearing database) and this information is displayed to the user. The system has one knowledge-base (Table 2.21) which gives advice for suitability of different seal types for a particular application on the user's request. Fig.3.8 shows the screen printout of the recommendations made.

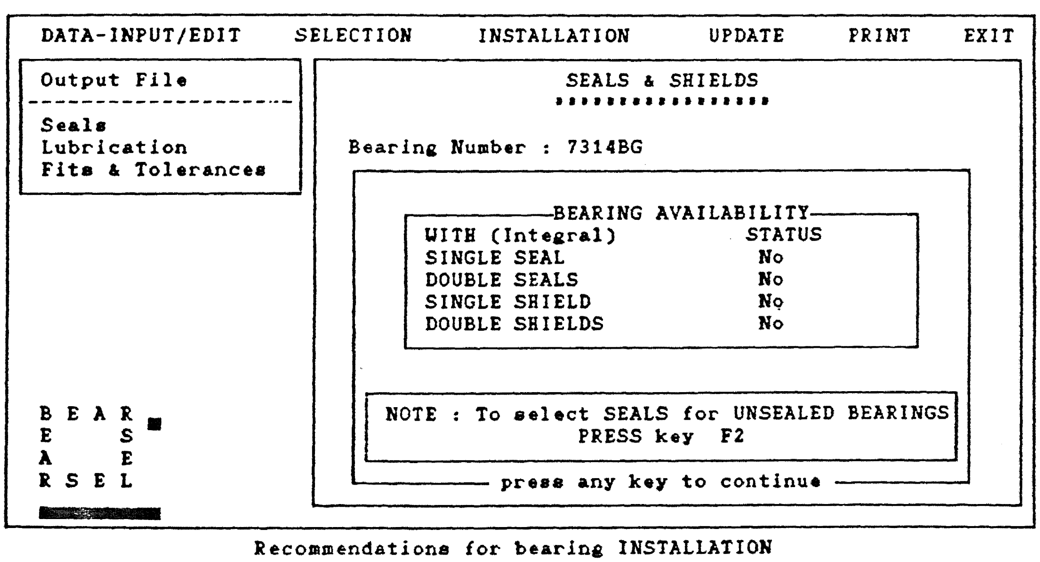


Figure 3.8: Screen printout of Seal recommendations

3.4.2 Selection of Lubrication Method

The system has one rule set and knowledge base (Table 2.13) which is used to decide which lubrication method (oil or grease) should be used for given conditions (Section 2.5). For grease lubrication a second rule set and a knowledge base is used to recommend the grease type and its consistency (NLGI grade) etc (Section 2.5.1). Afterwards using input data and knowledge, relubrication period and amount of grease required are determined (Eqns. 2.42 and 2.43). For oil lubrication the viscosity of oil is determined using the model described in Section 2.5.2 .

All the recommendations are displayed finally for the user. Fig. 3.9 shows screen printout of the lubrication recommendations.

3.4.3 Selection of ISO Fits and Tolerances

The system has one set of rules which represents general knowledge about applications and bearings. which is used to infer the rotating part (shaft, housing or both), rotating conditions on inner and outer bearing ring, and the type of fit (interference or clearance) to be used etc. A second rule set contains rules which are specialised at recommending ISO shaft, housing fits for a given bearing. This set uses values or knowledge that is inferred by the previous set. Both sets are performed with backward chaining inference (Section 2.6; Tables 2.17–2.20).

There is a third backward chaining rule set which is used to infer recommended tolerances for a given bearing fit type (Tolerance Tables, ISO :BS 4500). All the recommendations about the fit type, fits and tolerances for shaft and housing are displayed for the user. Fig.3.10 shows the screen print of such fits recommendations.

3.5 Update Database (UPDATE)

Rolling element bearings, being the most widely used mechanical components, have attracted continuous research in this field resulting in improvement in existing bearings and introduction of new bearings. To incorporate this dynamism this module has been designed and implemented by facilitating the user to update the bearing databases. Four options are provided as follows :

- Add
- Edit
- View
- Delete

Simillar to previous modules, the user has to select the bearing type first and accordingly the system retrieves the relevent bearing database. In add procedure, to avoid duplication, the pre existance of the bearing record is checked by scanning the database for bearing

```
DATA-INPUT/EDIT   SELECTION   INSTALLATION   UPDATE   PRINT   EXIT

Output File                      LUBRICATION DETAILS
--------------------
Seals                   Bearing Number : 7314BG
Lubrication
Fits & Tolerances                 SPECIFICATIONS
                        LUBRICANT        :  Oil
                        VISCOSITY(cst)   :  14.79
                        VISCOSTY INDEX   :  Medium OR High

                  ADVICE :For centralised oil lubrication system
                          same oil may also be used for the bearing
B E A R
E     S
A     E
R S E L                  Press any key to continue

            Recommendations for bearing INSTALLATION
```

```
DATA-INPUT/EDIT   SELECTION   INSTALLATION   UPDATE   PRINT   EXIT

Output File                      LUBRICATION DETAILS
--------------------
Seals                   Bearing Number : 7314BG
Lubrication
Fits & Tolerances                 SPECIFICATIONS
                        LUBRICANT             :    GREASE
                        GREASE CODE           :    L-XG-271
                        QUANTITY REQD. (g)    :    52.50
                        REGREASE PERIOD(Hrs):      13933.20
                        NLGI No               :    2 OR 3

                  ADVICE :Fill grease upto 30-50 % of free space
                          Over packing may cause over heating
B E A R
E     S
A     E             NOTE : For GREASE CODE description press F2
R S E L                  Press any key to continue

            Recommendations for bearing INSTALLATION
```

Figure 3.9: Screen printouts of Lubrication recommendations

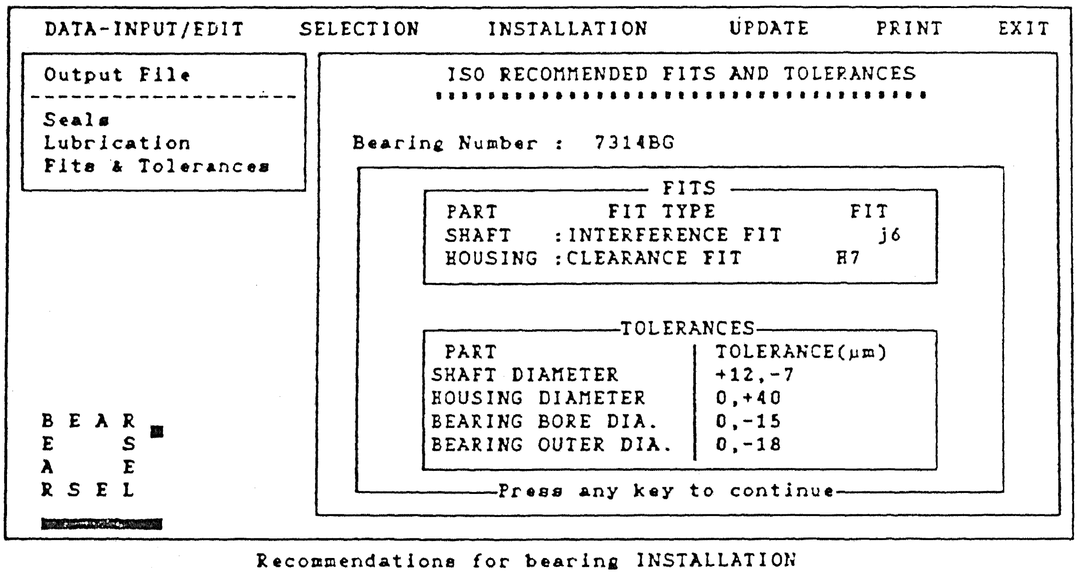


Figure 3.10: Screen printout of fits recommendations

number and company name entered by the user. If bearing record is not found. the relevent bearing attributes are displayed in an appropriate format for the user to enter the values. Otherwise a message saying " Bearing already exists " is flashed on the screen.

In a similar way 'edit' and 'delete' procedure has been designed and implemented. In view option, all bearings available within database are displayed.

The flow chart of implementation procedure for this module is shown in Fig 3.12.

3.6 Printing (PRINT)

The main function of this module is to provide on-line printing facility to the user. This facility has been designed and implemented with four options, such as :

- Input
- Output (Bearings selected)
- Database
- Others

To get the hardcopy of any input, output or bearing database, the user has to select the desired file/database first. The system accordingly retrieves the relevent file/database to be printed and transfers this buffer in the appropriate format to the printer. The flow chart of implementation procedure for this module is shown in Fig.3.13 .

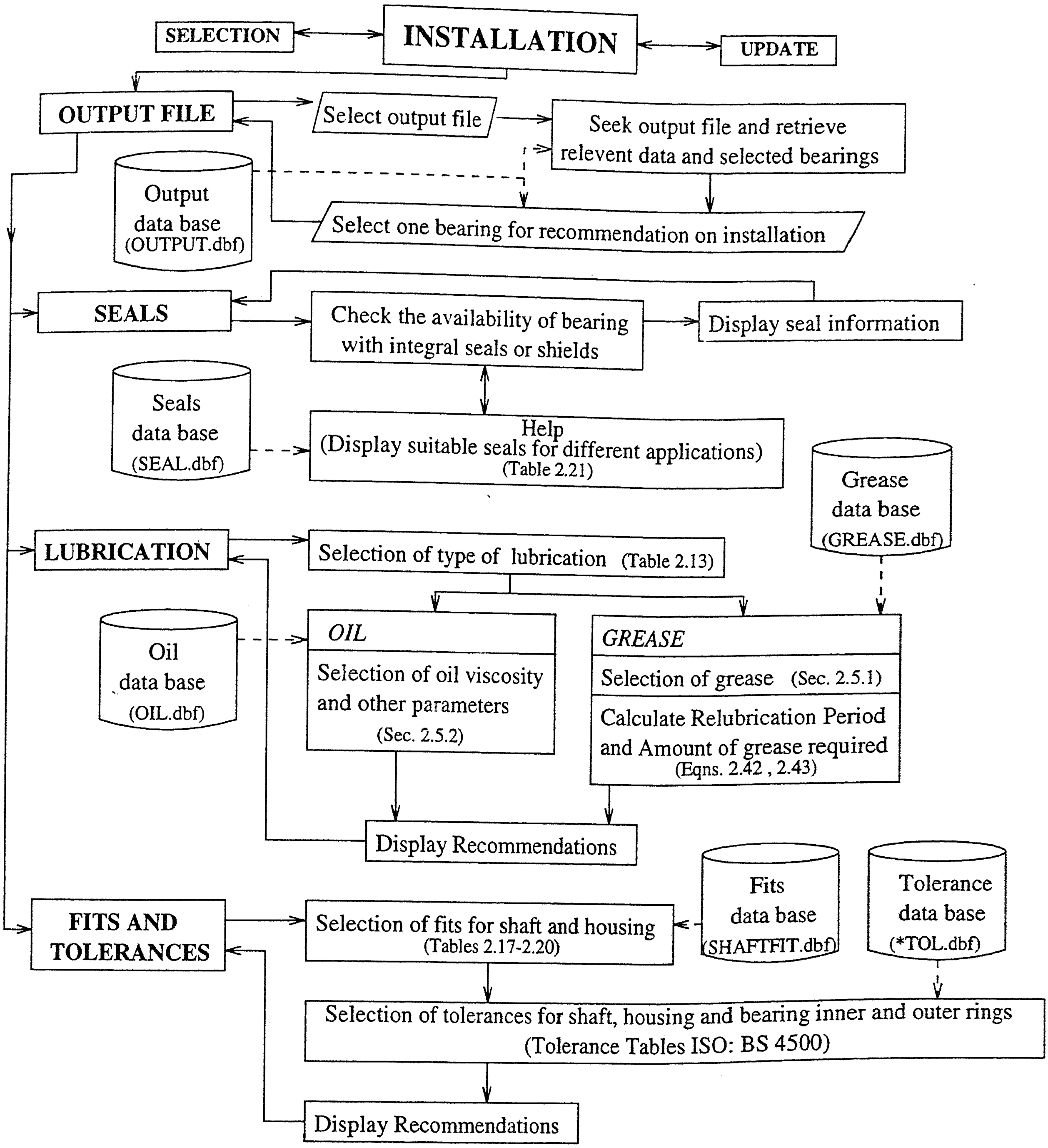


Figure 3.11: Flow chart: Implementation Procedure of INSTALLATION module

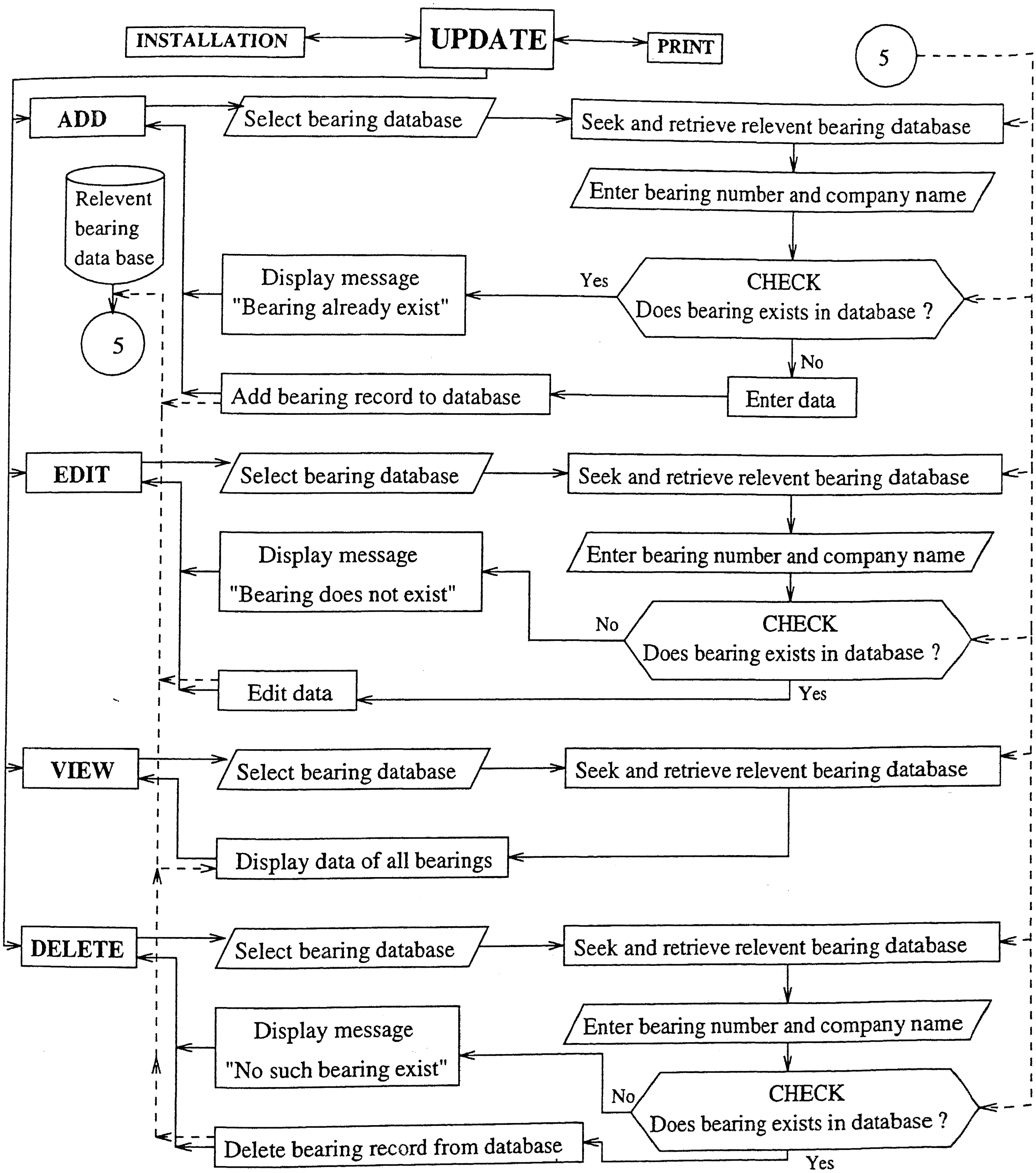


Figure 3.12: Flow chart: Implementation Procedure of UPDATE module

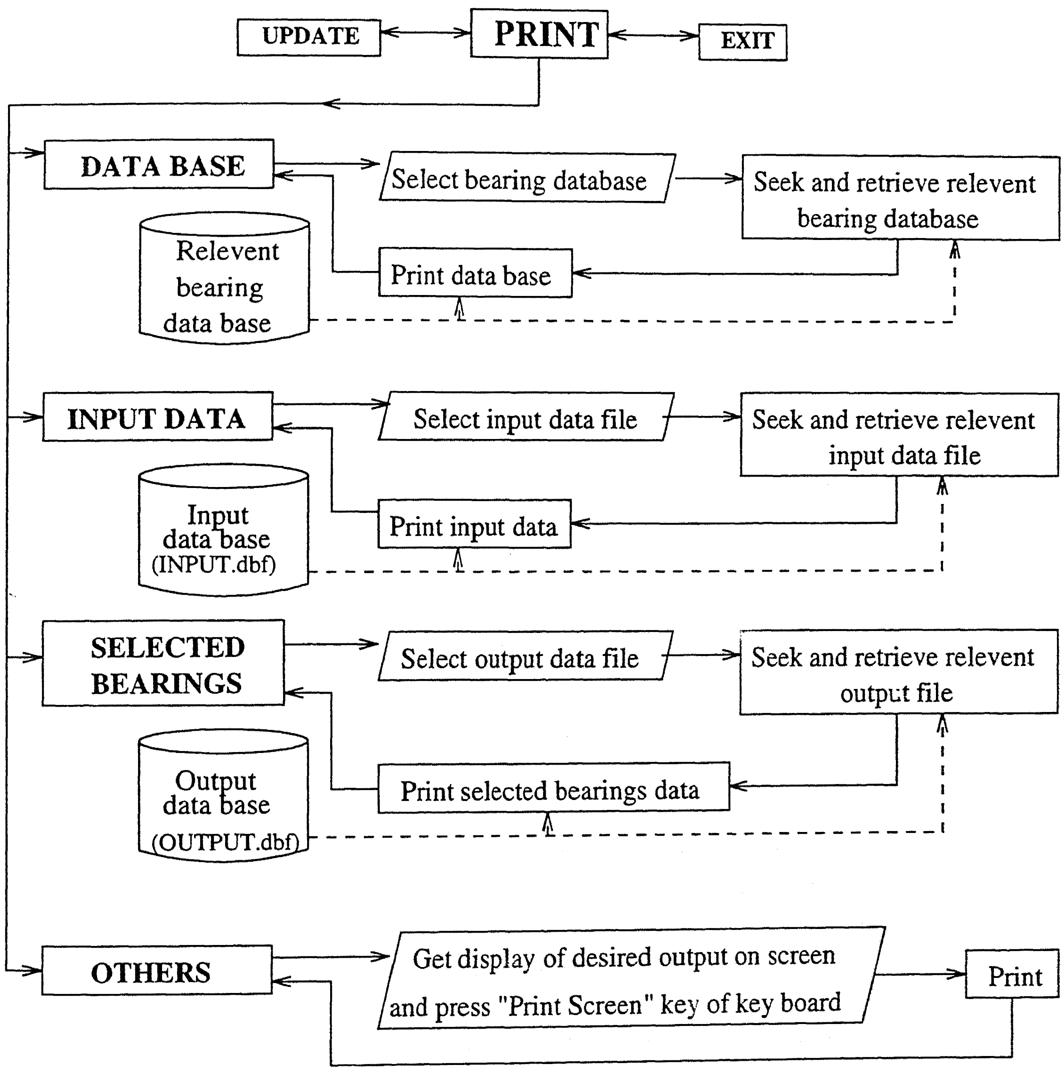


Figure 3.13: Flow chart: Implementation Procedure of PRINT module

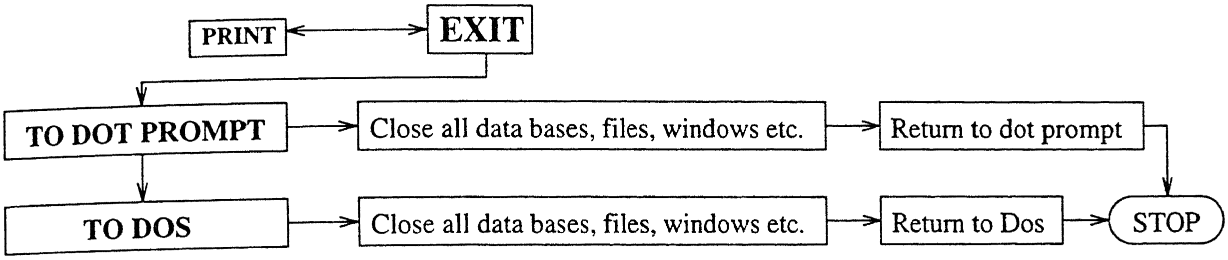


Figure 3.14: Flow chart: Implementation Procedure of EXIT module

3.7 Quiting from the System (EXIT)

After bearing selection is finished and saved, the user may quit the system to either dot prompt or to DOS using this module. Before quiting finally, the system closes all open databases, files and releases all windows, memory variables etc. The implementation procedure is shown in Fig. 3.14 .

3.8 How to use BEARSEL ?

To run the system correctly and efficiently the working with BEARSEL is summarised as follows :

Step 1 Go to **Data-Input/Edit** option of the main menu and enter the required inputs in the order they are displayed on the screen (top to bottom then left to right for sub and sub-sub-menus). Make sure to enter each and every small piece of input, ignorance may affect the final results (Bearings selected).

Step 2 Get display of input data to check the correct entry then save it for future use.

Step 3 Go to the **Selection** option of main menu and select the input file. Now select the bearing types.

Step 4 Out of the diplayed list of suitable bearing types, select one type and then for this bearing type select bearings in three stages in the order based on load ratings, limiting speed and dimensional limits. If in between of any stage no suitable bearings are found, select another bearing type. Finally save these bearings in output file.

Step 5 Go to **Installation** option of the main menu, select finally one bearing and get recommendation for seals, lubrication and fits.

Step 6 Go to **Print** option to get print-out or to **Update** option to update bearing databases.

Step 7 Quit the system with **Exit** option.

3.9 BEARSEL knowledge base and program files

For selection at various steps, the system uses several knowledge base. These are structured in 36 database files whose list with purpose is shown in Table 3.2. The knowledge for these databases has been gathered after extensive study of various manufacturers catalogues [10,12], journals [3,4], books [14,15], hand books [8,9] etc. and expert opinions.

The list of various program files with purpose is described in Table 3.3 . The system summary, tree diagram, structures of all databases and list of different files etc. are shown in Appendix B.

3.10 System Outputs

The outputs of the system are displayed, in appropriate formats, on the screen at various stages of the system run. Hard copies may also be obtained on printer. Sample screen outputs are shown in Appendix A.

Name	Purpose
	Data storage of :
ACBB1.DBF	Angular contact ball bearings (single row)
ACBB2.DBF	Angular contact ball bearings (paired)
ACBB3.DBF	Angular contact ball bearings (double row)
ACTBBSD.DBF	Angular cont. thru. ball bearings (sing. dirction)
ACTBBDD.DBF	Angular cont. thru. ball bearings (doub. dirction)
BRB.DBF	Barrel roller bearings
CRB1.DBF	Cylindrical roller bearings (separable rings)
CRB3.DBF	Cylindrical roller bearings (non-separable rings)
CRBDR.DBF	Cylindrical roller bearings (double row)
CRTB.DBF	Cylindrical roller thrust bearings
DGBB1.DBF	Deep groove ball bearings (single row)
DGBB2.DBF	Deep groove ball bearings (double row)
FPCBB.DBF	Four point contact ball bearings
MB.DBF	Megneto bearings
NRB1.DBF	Needle roller bearings
NRB4.DBF	Combined needle roller/ball bearings
NRB5.DBF	Combined needle roller/thrust ball bearings
NRTB.DBF	Needle roller thrust bearings
SABB.DBF	Self aligning ball bearings
SB.DBF	Spindle bearings
SRB1.DBF	Spherical roller bearings
SRTB.DBF	Spherical roller thrust bearings
TBB1.DBF	Thrust ball bearings (single direction)
TBB2.DBF	Thrust ball bearings (double direction)
TRB.DBF	Taper roller bearings
SEAL.DBF	Seal types for different applications
SELECT.DBF	Bearing type suitability and capability
GREASE.DBF	Grease types for different applications
SHAFTFIT.DBF	Fit types for shafts
SHAFTTOL.DBF	Tolerances for shafts
HOUSETOL.DBF	Tolerances for housings
FLD_DES.DBF	Description for field names of data-bases
SLHELP.DBF	Sudden load type for different applications
OUTPUT.DBF	Finally selected bearings
INPUT.DBF	Input data
LIFEHELP.DBF	requisite life for different applications

Table 3.2: Knowledge-Base of BEARSEL

Name	Purpose
	Calculation of C_{req} and sorting of :
AC_BB1.PRG	Angular contact ball bearings (single row)
AC_BB2.PRG	Angular contact ball bearings (paired)
AC_BB3.PRG	Angular contact ball bearings (double row)
ACTBBSD.PRG	Angular cont. thru. ball bearings (sing. dirction)
ACTBBDD.PRG	Angular cont. thru. ball bearings (doub. dirction)
BR_B.PRG	Barrel roller bearings
CR_B1.PRG	Cylindrical roller bearings (separable rings)
CR_B3.PRG	Cylindrical roller bearings (non-separable rings)
CR_BDR.PRG	Cylindrical roller bearings (double row)
CR_TB.PRG	Cylindrical roller thrust bearings
DGBB1.PRG	Deep groove ball bearings (single row)
DGBB2.PRG	Deep groove ball bearings (double row)
FPCBB.PRG	Four point contact ball bearings
MB.PRG	Megneto bearings
NRB1.PRG	Needle roller bearings
NRB4.PRG	Combined needle roller/ball bearings
NRB5.PRG	Combined needle roller/thrust ball bearings
NRTB.PRG	Needle roller thrust bearings
SA_BB.PRG	Self aligning ball bearings
SB.PRG	Spindle bearings
SR_B1.PRG	Spherical roller bearings
SR_TB.PRG	Spherical roller thrust bearings
TBB1.PRG	Thrust ball bearings (single direction)
TBB2.PRG	Thrust ball bearings (double direction)
TRB.PRG	Taper roller bearings

Table 3.3: Program Files of BEARSEL

Name	Purpose
MAIN.PRG	Master program file
HEAD.PRG	To display first screen of the system
PROCED2.PRG	Procedure file containing commen procedures
SPEED.PRG	To get speed input data
LOAD1.PRG	To get load input data
TEMPAR.PRG	To get temperature input data
SUDDEN.PRG	To get sudden load input data and calculate shock factor
RELIBITY.PRG	To get reliability input data and calculate a_1
LIFE1.PRG	To get life input data
DIMEN1.PRG	To get bearing dimension input data
OPCON1.PRG	To get operating conditions input data
DISPDATA.PRG	To display input data
IDSAVE.PRG	To save input data
ONLYRL1.PRG	To sort bearing types for only radial load
ONLYTL1.PRG	To sort bearing types for only thrust load
COMLOAD1.PRG	To sort bearing types for combined load
SELECT1.PRG	To select input file and input data retrieval
SELECT2.PRG	To select bearing types
SELECT3.PRG	To sort bearings based on speed limits
SELECT4.PRG	To sort bearings based on dimensioal limits
ODSAVE.PRG	To save selected bearings
INSTAL.PRG	To select output file and data retrieval
LUBRIC.PRG	To select lubrication
BEARFIT.PRG	To select the fits and tolerances
SEALS.PRG	To select the seals
DBMAN.PRG	To update bearing data-bases
BIP.PRG	To display description of database fields
PRINTDB.PRG	To print bearing data-base
PRINTID.PRG	To print input data
PRINTOT.PRG	To print any displayed screen
PRINTBS.PRG	To print selected bearings

Table 3.3: (continued ...)

Chapter 4

Results and Discussions

The present system, for a given application, first prepares a priority list of suitable bearing types based on certain selection criteria. After the selection of one of the suitable bearing type by the user, the system selects the optimum size bearing(s). The system also recommends the sealing and lubrication methods as well as fits and tolerances to be used while installing the bearing. In this chapter, few examples have been discussed along with their resuls in the form of screen printouts.

4.1 Example 1 : Bearing selection for a blower

This example considers the bearing selection for a medium size fresh air blower, with overhung arrangement, used in high speed ventilation plants (courtesy: [14], pp 406-409).

4.1.1 Inputs

The design of blower is based on the following data :

Input power	$N = 120\,kW$
Speed	$n = 3000\,min^{-1}$
Axial load	$F_a = 6\,kN$
Weight of impeller	$G_f = 3\,kN$
Weight of shaft	$G_w = 0.45\,kN$
Weight of coupling	$G_k = 0.15\,kN$
Fresh air temperature	$\approx\ 30^oC$
Ambient temperature	$\approx\ 35^oC$

The shaft diameter of 70 mm at two bearing locations is determined by the design. Fig. 4.1 shows the bearing load diagram. The imbalance due to gradual dirt accumulation on the impeller is also added to the weight of impeller while calculating radial bearing loads.

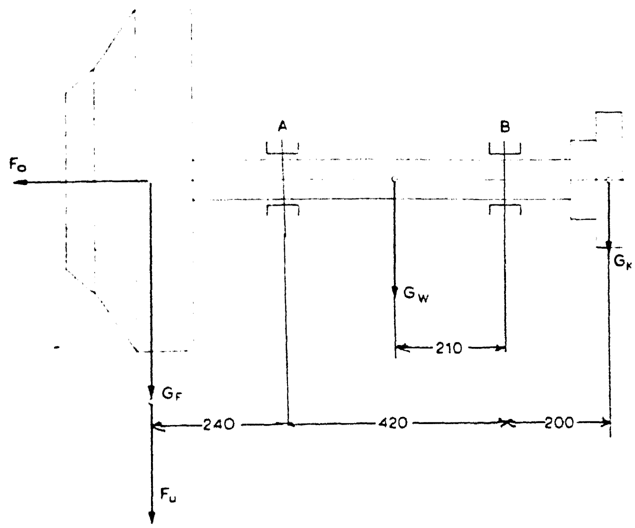


Figure 4.1: Load diagram for the bearings of blower

The loads acting on the two bearing locations are as follows :

bearing A :	$F_r = 7.23\,kN$	$F_a = 0$
bearing B :	$F_r = 2.12\,kN$	$F_a = 6\,kN$

The bearing for the location B is selected where shaft is the rotating part and bearing function is 'locating'. High speed operation makes running accuracy critical and, rigidity and low friction important. The input screen printout is shown in Fig. 4.2.

4.1.2 Outputs

The system suggests the angular contact ball bearing (paired) as most suitable bearing type (shown in Fig. 4.3). The selected optimum sized bearings alongwith recommendations for sealing, lubrication and fits (for the bearing 7314 BG) are shown in Figures 4.4 to 4.7 respectively.

4.1.3 Discussions

The system selects the angular contact ball bearing (ACBB2) as most suitable. While eliminating unsuitable bearing types, system proceeds as follows :

1. Elimination based on bearing speed, like SRTB (having maximum speed available lower than the required (see Table 2.1)).

2. Elimination of bearing types not suitable for combined load, like ACTBBDD, CRB1, NRB1, TBB1 ...etc. (see Table 2.1).

```
                                INPUT DATA DISPLAY
  SPEED         LOAD                                    RELIABILITY
(Constant)   **RADIAL**          **THRUST**          RELIABILITY(%) : 90
             (Constant)  (Constant)   DIRECTION
RPM VALUE    VALUE       VALUE        Single                    LIFE
  3000         2120        6000                      OPERATING HRS :        40000
                                      **SUDDEN**
                                                               TEMPARATURE
                                      Negligible      MAXIMUM TEMP. :          70
                                                      MINIMUM TEMP. :          30

                                                              DIMENSIONS
                                                     BORE DIA.: MAX.   80 MIN.   70
                                                     OUTER DIA: MAX.    0 MIN.    0
                                                     WIDTH    : MAX.    0 MIN.    0

                                  OPRATING CONDITIONS
RUNNING ACCURACY       :  4 |RUNNING QUIETNESS: 1|0 -> UNDESIRABLE:
SELF ALIGN. CAPABILITY:   1 |LOW FRICTION     : 3|1 -> USUAL      :
RADIAL RIGIDITY        :  3 |MAINTENANCE EASE : 1|3 -> DESIRABLE  :
AXIAL RIGIDITY         :  3 |COST             : 1|4 -> CRITICAL   :

                             PRESS ANY KEY TO CONTINUE
```

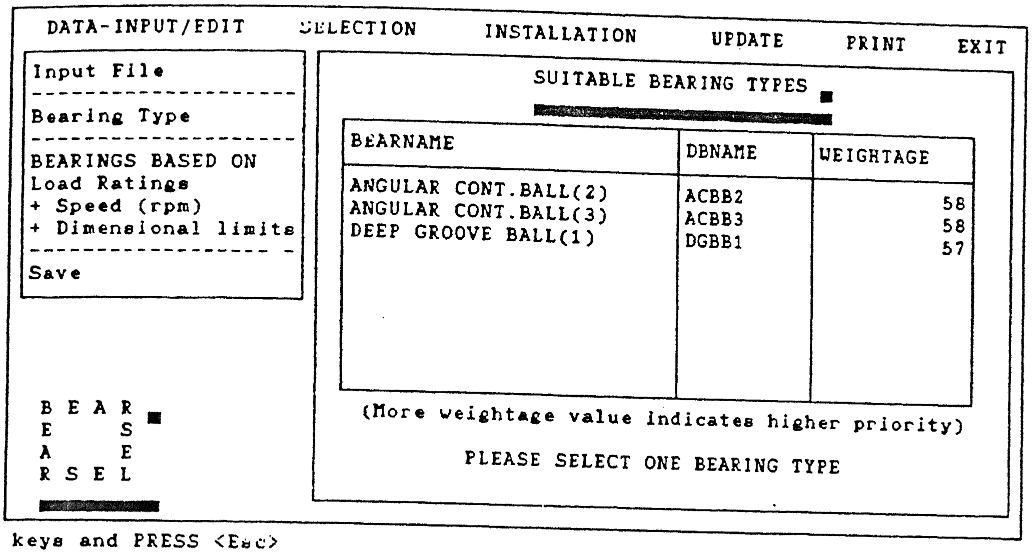
Figure 4.2: Screen printout of Input for Example 1

3. Elimination based on Admissible load ratio (F_a/F_r = 2.83), like CRB3, DGBB2, NRB4 ...etc. (see Table 2.1).

4. Elimination based on Bearing Function (locating criteria) like, ACTBBSD, MB ...etc. (see Table 2.1).

5. Elimination based on Running Accuracy as critical like, NRB4, NRB5, SABB ...etc. (see Table 2.3).

In real application angular contact ball bearing (paired), 7314.B.TVP, is being used with k6 and J7 fits for inner and outer bearing rings. Use of Lithium soap grease is quoted [14]. Hence system results appear to be in excellent agreement with actual practice.



DATA-INPUT/EDIT SELECTION INSTALLATION UPDATE PRINT EXIT

Input File
Bearing Type
BEARINGS BASED ON
Load Ratings
+ Speed (rpm)
+ Dimensional limits
Save

SUITABLE BEARING TYPES

BEARNAME	DBNAME	WEIGHTAGE
ANGULAR CONT.BALL(2)	ACBB2	58
ANGULAR CONT.BALL(3)	ACBB3	58
DEEP GROOVE BALL(1)	DGBB1	57

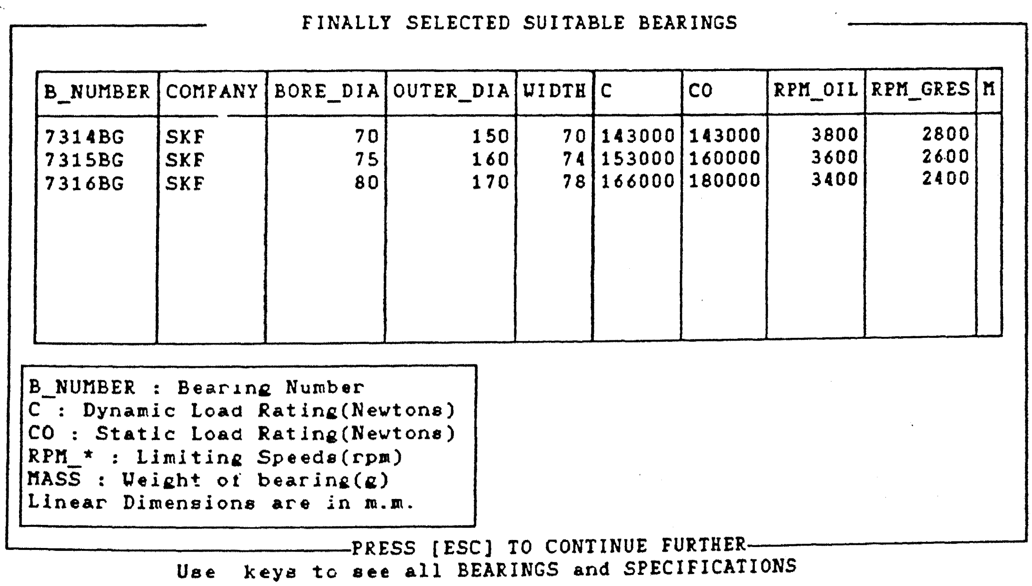
(More weightage value indicates higher priority)

PLEASE SELECT ONE BEARING TYPE

B E A R
E S
A E
R S E L

keys and PRESS <Esc>

Figure 4.3: Screen printout of suitable bearing types for Example 1



FINALLY SELECTED SUITABLE BEARINGS

B_NUMBER	COMPANY	BORE_DIA	OUTER_DIA	WIDTH	C	CO	RPM_OIL	RPM_GRES	M
7314BG	SKF	70	150	70	143000	143000	3800	2800	
7315BG	SKF	75	160	74	153000	160000	3600	2600	
7316BG	SKF	80	170	78	166000	180000	3400	2400	

B_NUMBER : Bearing Number
C : Dynamic Load Rating(Newtons)
CO : Static Load Rating(Newtons)
RPM_* : Limiting Speeds(rpm)
MASS : Weight of bearing(g)
Linear Dimensions are in m.m.

PRESS [ESC] TO CONTINUE FURTHER

Use keys to see all BEARINGS and SPECIFICATIONS

Figure 4.4: Screen printout of finally selected bearings for Example 1

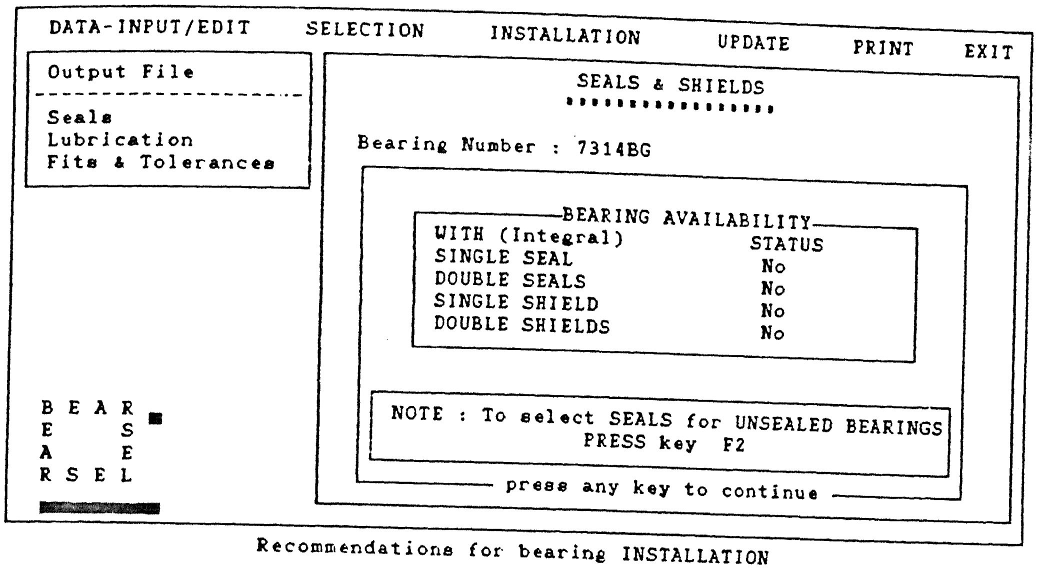


Figure 4.5: Screen printout of recommendations for seals for Example 1

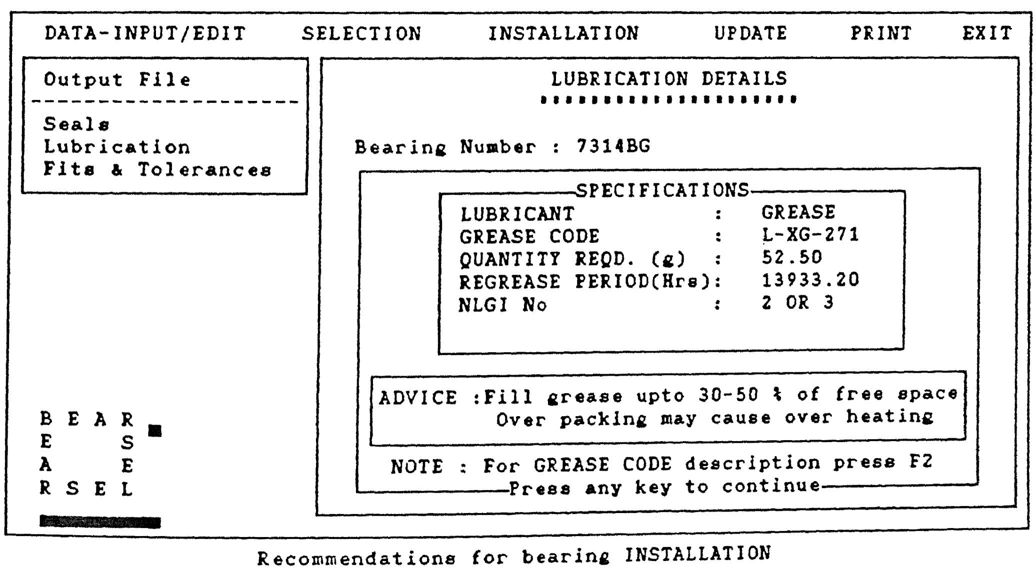


Figure 4.6: Screen printout of recommendations for lubrication for Example 1

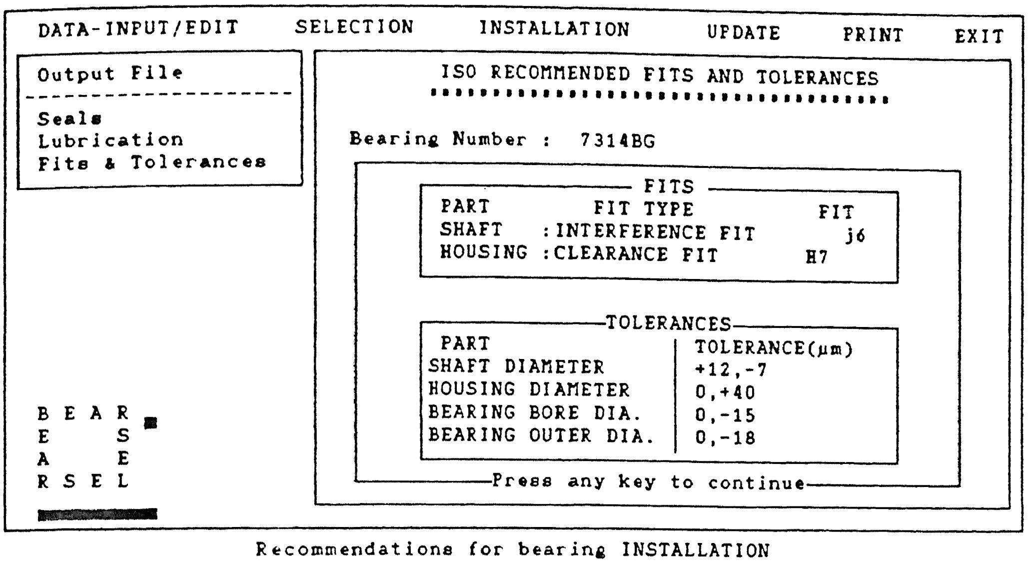


Figure 4.7: Screen printout of recommendations for fits for Example 1

4.2 Example 2 : Bearing selection for the traction motor of an electric locomotive

Traction motors do not operate continuously or witL a constsnt output. The operation is intermittent and the loads on the traction motor bearings vary considerably in magnitude and direction (courtesy: [14], pp 416-419).

4.2.1 Inputs

The following data are available for the bearing calculation :

Hourly output power	$N_h = 1250\, kW$
Hourly speed	$n_h = 1300\, min^{-1}$
Maximum rotational speed	$n_{max} = 1500\, min^{-1}$
Maximum travel speed	$v_{max} = 200\, km/h$
Armature weight	$G_L = 13.5\, kN$
Pinion pitch circle diameter	$d_o = 521.3\, mm$
Pressure angle	$\alpha_E = 20^o$
Spiral angle	$\beta = 4^o$

Fig. 4.8 shows the bearing load diagram.

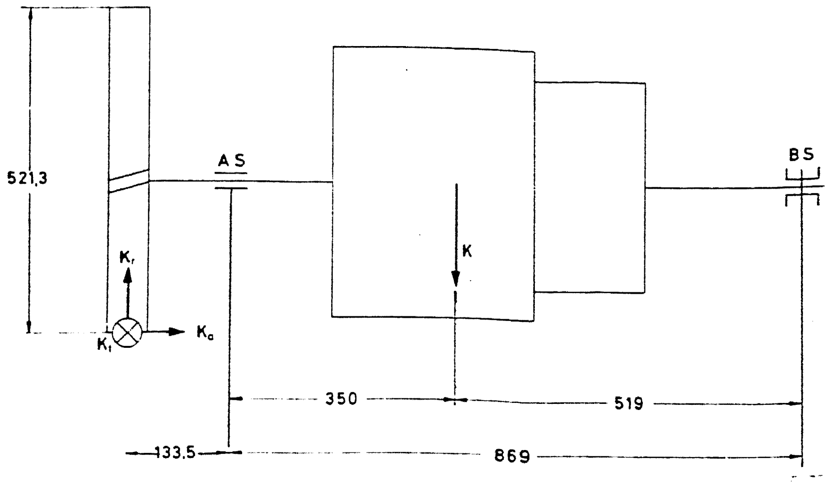


Figure 4.8: Load diagram for the bearings of traction motor

The determined tooth load acting on the pinion based on hourly output calculation are as follows :

Tangential load	$K_t = 22.9\ kN$
Radial load	$K_r = 8.36\ kN$
Axial load	$K_a = 1.6\ kN$

The bearings are additionally loaded by the rotor weight, imbalance loads and shock loads occuring in operation. The changing direction of travel of the locomotive is considered and, as a rule, 50 % of the mileage is assumed for either direction of travel. The shaft diameters of 130 and 90 mm at two bearing locations AS and BS are determined by the design. The bearing loads for both direction of rotation acting on the two bearing locations AS and BS are as follows :

Bearing location	Bearing loads [kN]	
	anticlockwise rotation	*clockwise rotation*
AS	$F_r = 13.67$	$F_r = 13.55$
BS	$F_r = 6.1;\ F_a = 0.8$	$F_r = 6.575;\ F_a = 0.8$

The bearing for the location BS is selected where operating conditions makes running accuracy and low friction, critical and radial rigidity important. The input screen printout is shown in Fig. 4.9.

4.2.2 Outputs

For bearing at location BS the system suggests the angular contact ball bearing and cylindrical roller bearing as most suitable bearing type (shown in Fig.4.10). The selected

```
                                   INPUT DATA DISPLAY
 SPEED                          LOAD                          RELIABILITY
(Constant)   **RADIAL**            **THRUST**           RELIABILITY(%) : 90
             (Step Load)  (Constant)   DIRECTION
RPM VALUE    STEPS:  2    VALUE        Double                  LIFE
  1300        VALUE  | %    800                         RUNNING KMS(million): 3.00
               6100 | 50              **SUDDEN**        WHEEL DIA. :          0.52
               6575 | 50
                                      Medium Shock            TEMPARATURE
                                                         MAXIMUM TEMP. :        90
                                                         MINIMUM TEMP. :        30

                                                               DIMENSIONS
                                                        BORE DIA.: MAX.  95 MIN.  90
                                                        OUTER DIA: MAX.   0 MIN.   0
                                                        WIDTH  :   MAX.   0 MIN.   0

                             OPRATING CONDITIONS
RUNNING ACCURACY         :  4|RUNNING QUIETNESS: 1|0 -> UNDESIRABLE:
SELF ALIGN. CAPABILITY:     1|LOW FRICTION     : 4|1 -> USUAL      :
RADIAL RIGIDITY          :  3|MAINTENANCE EASE : 1|3 -> DESIRABLE  :
AXIAL RIGIDITY           :  1|COST             : 1|4 -> CRITICAL   :

                          PRESS ANY KEY TO CONTINUE
```

Figure 4.9: Screen printout of Input for Example 2

optimum sized bearings alongwith recommendations for sealing, lubrication and fits (for the cylindrical roller bearing NJ 318) are shown in Figures 4.11 to 4.14 respectively.

4.2.3 Discussions

The system provides more options to the user by selecting bearings of more than one type. In real application cylindrical roller bearing NJ318.M, is used lubricated with Lithium soap grease. Due to shock type and frequently very high loads relatively tight fits are choosen (n5 and k6 for inner and outer bearing rings).

Comparison of system results with actual application data validates the system functionality.

DATA-INPUT/EDIT SELECTION INSTALLATION UPDATE PRINT EXIT

Input File

Bearing Type

BEARINGS BASED ON
Load Ratings
+ Speed (rpm)
+ Dimensional limits

Save

SUITABLE BEARING TYPES

BEARNAME	DBNAME	WEIGHTAGE
ANGULAR CONT.BALL(2)	ACBB2	59
DEEP GROOVE BALL(1)	DGBB1	59
CLYNDRICAL ROLLER(3)	CRB3	56

(More weightage value indicates higher priority)

PLEASE SELECT ONE BEARING TYPE

B E A R
E S
A E
R S E L

keys and PRESS <Esc>

Figure 4.10: Screen printout of suitable bearing types for Example 2

FINALLY SELECTED SUITABLE BEARINGS

B_NUMBER	COMPANY	BORE_DIA	OUTER_DIA	WIDTH	C	CO	RPM_OIL	RPM_GRES
NJ318	SKF	90	190	43	220000	160000	3800	3200
NJ2318	SKF	90	190	64	300000	240000	3400	2800
NUP218	SKF	90	160	30	134000	100000	4500	3800
NJ418	SKF	90	225	54	345000	260000	3400	2800
NJ2218	SKF	90	160	40	186000	150000	4300	3600
NUP2218	SKF	90	160	40	186000	150000	4300	3600
NJ218	SKF	90	160	30	134000	100000	4500	3800
NUP2318	SKF	90	190	64	300000	240000	3400	2800
NUP318	SKF	90	190	43	220000	160000	3800	3200

B_NUMBER : Bearing Number
C : Dynamic Load Rating(Newtons)
CO : Static Load Rating(Newtons)
RPM_* : Limiting Speeds(rpm)
MASS : Weight of bearing(g)
Linear Dimensions are in m.m.

PRESS [ESC] TO CONTINUE FURTHER

Use keys to see all BEARINGS and SPECIFICATIONS

Figure 4.11: Screen printout of finally selected bearings for Example 2

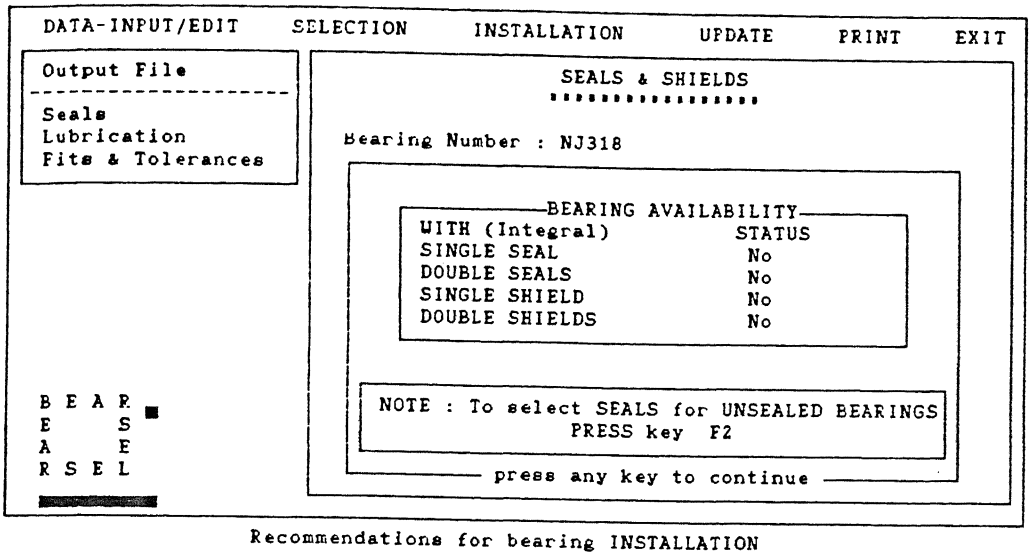


Figure 4.12: Screen printout of recommendations for seals for Example 2

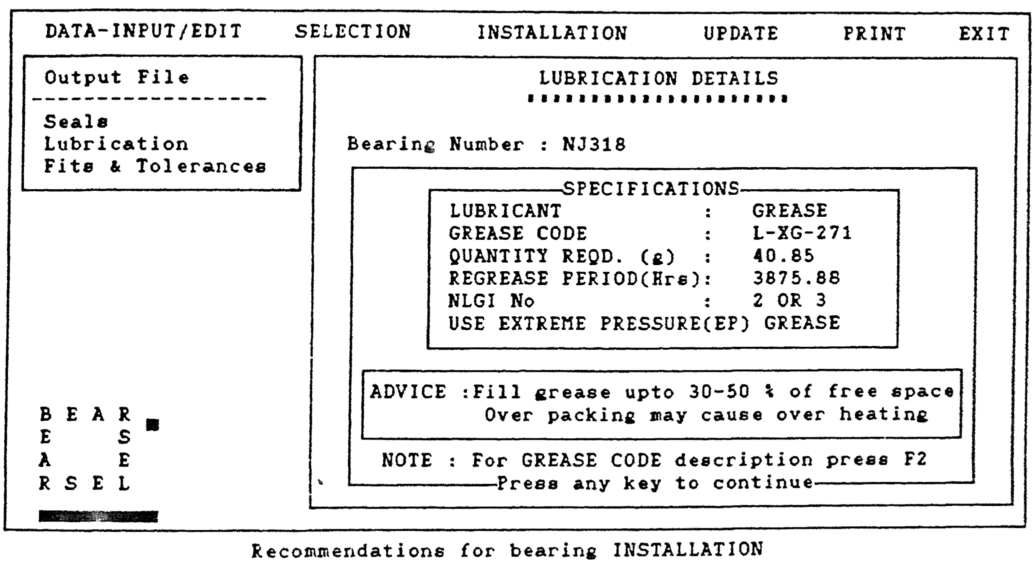


Figure 4.13: Screen printout of recommendations for lubrication for Example 2

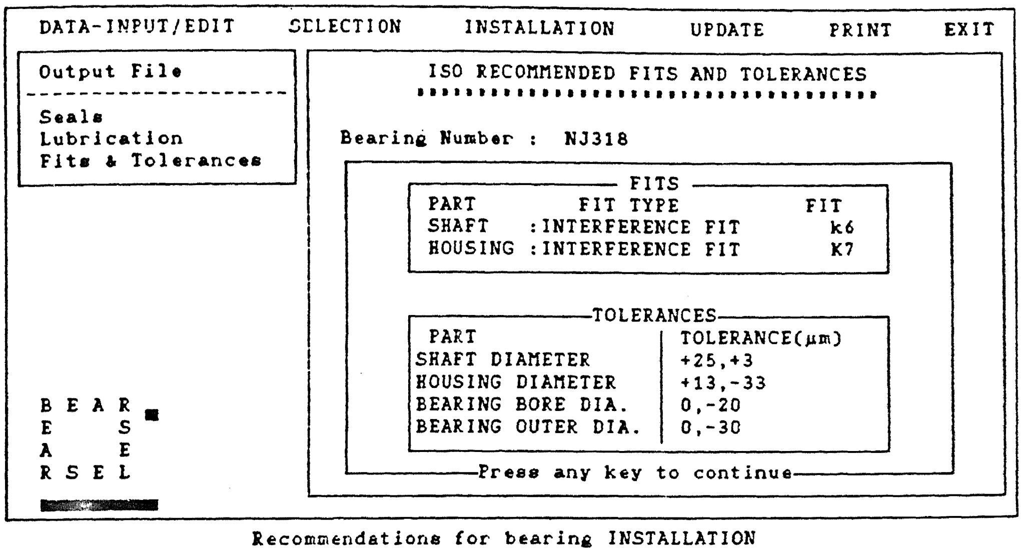


Figure 4.14: Screen printout of recommendations for fits for Example 2

4.3 Example 3 : Bearing selection for a ship propeller thrust block

The thrust block is the locating bearing of the line shaft and transmits the propeller end thrust from the shaft to the ship. Apart from a small radial load from the shaft weight, the bearing is loaded by a purely axial load which acts forward or backward, depending on the direction of the propeller rotation. The thrust must feature self aligning capability to compensate for misalignment resulting from distortion of the ship's hull, shaft deflection and small mismatch of shaft and housing. The design of thrust block is based on the propeller thrust (depends on the engine output), speed and shaft diameter (courtesy: [14], pp 451-456).

4.3.1 Inputs

The following data are available for the bearing calculation :

	Normal load	Full load
Engine output	$N_1 = 258\,kW$	$N_2 = 316\,kW$
	$n_1 = 375\,min^{-1}$	$n_2 = 500\,min^{-1}$
Proportionate running times	$q_1 = 75\%$	$q_2 = 25\%$
Resulting axial loads	$F_{a1} = 49\,kN$	$F_{a2} = 60\,kN$

The minimum shaft diameter of 130 mm is to be used. The input screen printout is shown in Fig. 4.15.

```
                                   INPUT DATA DISPLAY
 SPEED              LOAD                                   RELIABILITY
(Vriable)   **RADIAL**|      **THRUST**               RELIABILITY(%) : 90
STEPS: 2   (Negligible)(Step Load)|  DIRECTION
VALUES  %           | STEPS:  2 |  Double                  LIFE
   375 |75          |  VALUE |% |                 OPERATING HRS :          30000
   500 |25          |  49000 |75| **SUDDEN**
       |            |  60000 |25|
       |            |        |  |  Negligible              TEMPARATURE
       |            |        |  |                  MAXIMUM TEMP. :          80
       |            |        |  |                  MINIMUM TEMP. :          30
       |            |        |  |
                                                           DIMENSIONS
                                                  BORE DIA.: MAX.  150 MIN.  130
                                                  OUTER DIA: MAX.    0 MIN.    0
                                                  WIDTH  :   MAX.    0 MIN.    0

                              OPRATING CONDITIONS
RUNNING ACCURACY        :  3|RUNNING QUIETNESS: 1|0 -> UNDESIRABLE:
SELF ALIGN. CAPABILITY: 4|LOW FRICTION       : 1|1 -> USUAL       :
RADIAL RIGIDITY         :  1|MAINTENANCE EASE  : 1|3 -> DESIRABLE   :
AXIAL RIGIDITY          :  3|COST              : 1|4 -> CRITICAL    :

                              PRESS ANY KEY TO CONTINUE
```

Figure 4.15: Screen printout of Input for Example 3

4.3.2 Outputs

The system suggests the Spherical roller bearing 22330 C, as most suitable bearing. The various system outputs are shown in Figures 4.16 to 4.20 respectively.

4.3.3 Discussions

System eleminate all the bearing types other than BRB, SABB, SRB1, and SRTB because self aligning capability is critical (see Table 2.3). Further, by ranking suitable bearing types, it gives top priority to spherical roller bearing because of its thrust and shock load capacities (see Table 2.1). In real application the author [14] suggests the use of spherical roller bearing 22328 ES, with k6 or m6 fit for shaft and H7 (loose fit) for housing. Comparison again validates the system results.

DATA-INPUT/EDIT SELECTION INSTALLATION UPDATE PRINT EXIT

Input File

Bearing Type

BEARINGS BASED ON
Load Ratings
+ Speed (rpm)
+ Dimensional limits

Save

SUITABLE BEARING TYPES

BEARNAME	DBNAME	WEIGHTAGE
DEEP GROOVE BALL(1)	DGBB1	44
SPHERICAL ROLLER	SRB1	43

(More weightage value indicates higher priority)

PLEASE SELECT ONE BEARING TYPE

B E A R
E S
A E
R S E L

keys and PRESS <Esc>

Figure 4.16: Screen printout of suitable bearing types for Example 3

FINALLY SELECTED SUITABLE BEARINGS

B_NUMBER	COMPANY	BORE_DIA	OUTER_DIA	WIDTH	C	CO	RPM_OIL	RPM_GR
22330C	SKF	150	320	108	1120000	1040000	1400	1000

B_NUMBER : Bearing Number
C : Dynamic Load Rating(Newtons)
CO : Static Load Rating(Newtons)
RPM_* : Limiting Speeds(rpm)
MASS : Weight of bearing(g)
Linear Dimensions are in m.m.

PRESS [ESC] TO CONTINUE FURTHER

Use keys to see all BEARINGS and SPECIFICATIONS

Figure 4.17: Screen printout of finally selected bearings for Example 3

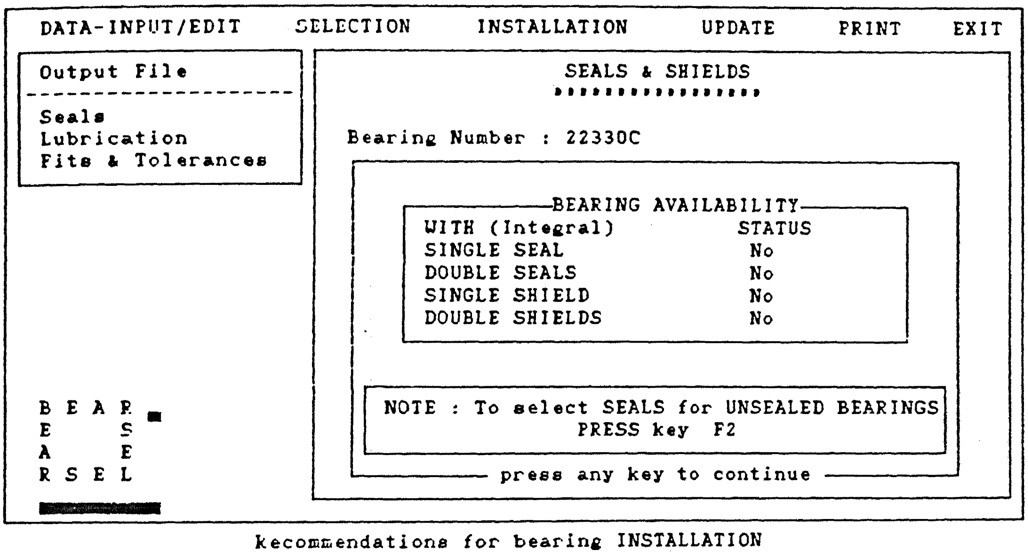


Figure 4.18: Screen printout of recommendations for seals for Example 3

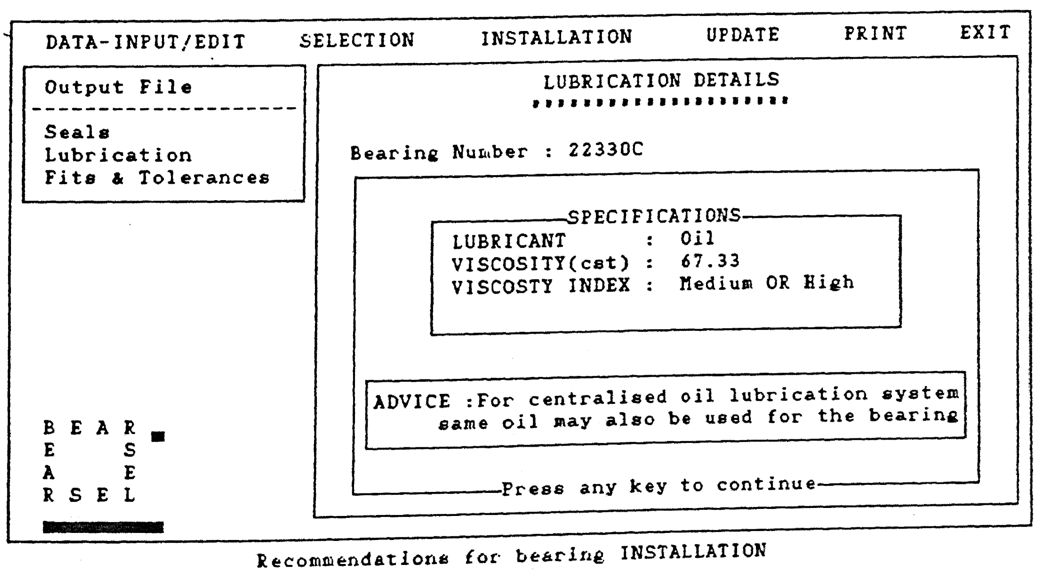


Figure 4.19: Screen printout of recommendations for lubrication for Example 3

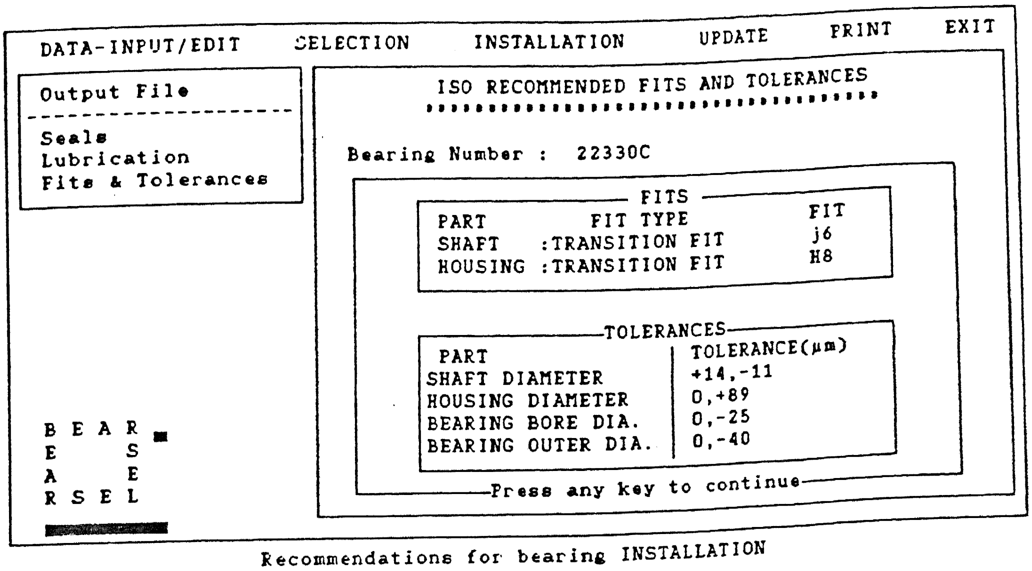


Figure 4.20: Screen printout of recommendations for fits for Example 3

4.4 Example 4 : Bearing selection for a conveyor belt idler

4.4.1 Inputs

The following data are available for the bearing calculation (courtesy: [14], pp 409-413) :

Capacity	3100 tonnes/h
Belt speed	3.5 m/s
Belt width	1000 mm
Trough angle	30^o
Idler diameter	108 mm
Axle diameter	20 mm
Idler length	380 mm
distance between two idler stations	1.5 m
Belt weight	25 kg/m
Weight of rotating parts of one idler	12 kg

Each idler is supported with two bearings with radial load $F_r = 1.38\,kN$ on each bearing at the idler speed of 620 min^{-1}. Application dictates the self aligning capability as critical. The input screen printout is shown in Fig. 4.21.

```
                                   INPUT DATA DISPLAY
 SPEED                          LOAD                              RELIABILITY
(Constant)   **RADIAL**            **THRUST**            RELIABILITY(%) : 90
             (Constant) (Negligible)  DIRECTION
RPM VALUE     VALUE                   Single                       LIFE
   620         1380                                      OPERATING HRS :       30000
                                    **SUDDEN**
                                                                TEMPARATURE
                                    Negligible           MAXIMUM TEMP. :          50
                                                         MINIMUM TEMP. :          30

                                                                DIMENSIONS
                                                         BORE DIA.: MAX.  25 MIN.  20
                                                         OUTER DIA: MAX. 105 MIN.  20
                                                         WIDTH  :   MAX.   0 MIN.   0

                             OPRATING CONDITIONS
RUNNING ACCURACY     :  3|RUNNING QUIETNESS: 3|0 -> UNDESIRABLE:
SELF ALIGN. CAPABILITY: 4|LOW FRICTION      : 3|1 -> USUAL      :
RADIAL RIGIDITY      :  1|MAINTENANCE EASE  : 1|3 -> DESIRABLE  :
AXIAL RIGIDITY       :  1|COST              : 1|4 -> CRITICAL   :

                             PRESS ANY KEY TO CONTINUE
```

Figure 4.21: Screen printout of Input for Example 4

4.4.2 Outputs

The system suggests the deep groove ball bearings 4204 B.TVH (FAG) and 6404 (SKF), as most suitable bearings. The screen printouts of various system outputs are shown in Figures 4.22 to 4.26 respectively.

4.4.3 Discussions

As self aligning capability is critical and cost, running accuracy, and low friction are important the system ranks the deep groove ball bearing (single row) at first place (see Table 2.3). Minimum shaft diameter determines the optimum bearing size.

4.5 Example 5 : Bearing selection for a crane runwheel

This example describes the selection of bearing for a runwheel of a steel mill crane which travels on its rails with four runwheels (courtesy: [14], pp 356-360).

4.5.1 Inputs

The following data are available for the bearing calculation :

DATA-INPUT/EDIT SELECTION INSTALLATION UPDATE PRINT EXIT

Input File

Bearing Type

BEARINGS BASED ON
Load Ratings
+ Speed (rpm)
+ Dimensional limits

Save

SUITABLE BEARING TYPES

BEARNAME	DBNAME	WEIGHTAGE
DEEP GROOVE BALL(1)	DGBB1	62
SPHERICAL ROLLER	SRB1	53
SELF ALIGNING BALL	SABB	49
BARREL ROLLER	BRB	46

(More weightage value indicates higher priority)

PLEASE SELECT ONE BEARING TYPE

B E A R
E S
A E
R S E L

keys and PRESS <Esc>

Figure 4.22: Screen printout of suitable bearing types for Example 4

FINALLY SELECTED SUITABLE BEARINGS

B_NUMBER	COMPANY	BORE_DIA	OUTER_DIA	WIDTH	C	CO	RPM_OIL	RPM_GRES
4204B.TVH	FAG	20	47	18	18000	11000	14000	10000
6404	SKF	20	72	19	23600	16600	13000	10000
4304B.TVH	FAG	20	52	21	23200	13700	13000	9500
6305	SKF	25	62	17	17300	11400	14000	11000
4205B.TVH	FAG	25	52	18	19300	12700	12000	9000
6405	SKF	25	80	21	27500	19600	11000	9000
4305B.TVH	FAG	25	62	24	31500	19300	10000	8500

B_NUMBER : Bearing Number
C : Dynamic Load Rating(Newtons)
CO : Static Load Rating(Newtons)
RPM_* : Limiting Speeds(rpm)
MASS : Weight of bearing(g)
Linear Dimensions are in m.m.

PRESS [ESC] TO CONTINUE FURTHER

Use keys to see all BEARINGS and SPECIFICATIONS

Figure 4.23: Screen printout of finally selected bearings for Example 4

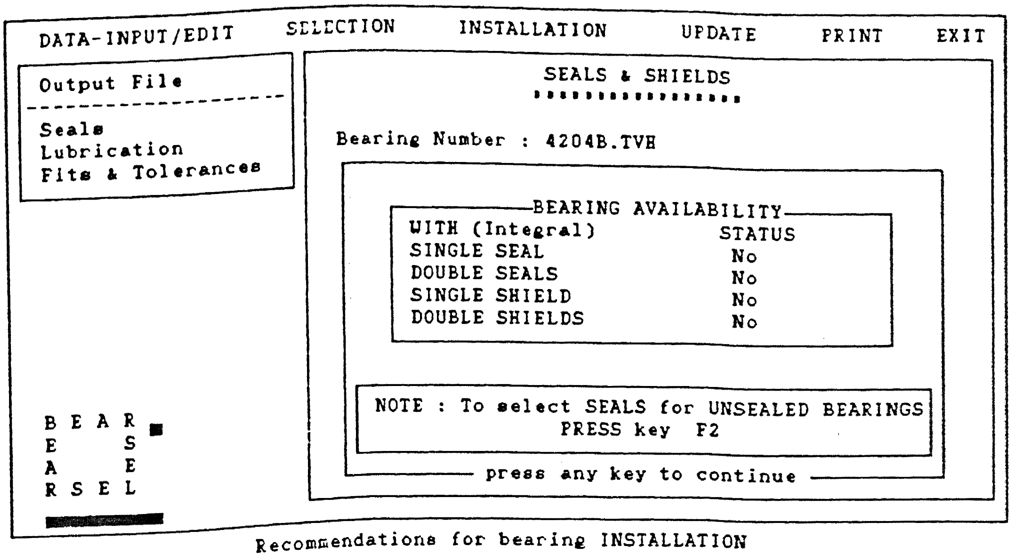


Figure 4.24: Screen printout of recommendations for seals for Example 4

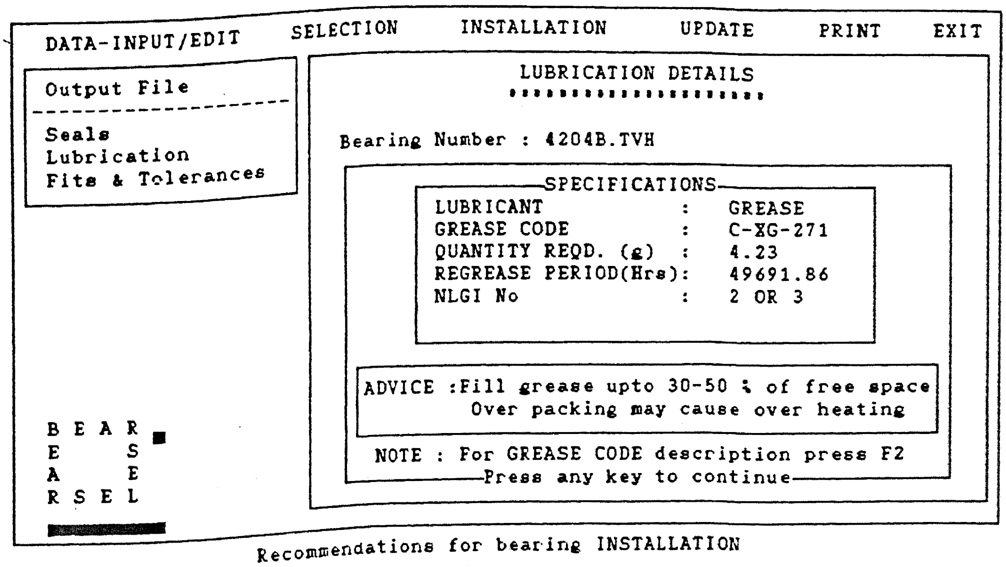


Figure 4.25: Screen printout of recommendations for lubrication for Example 4

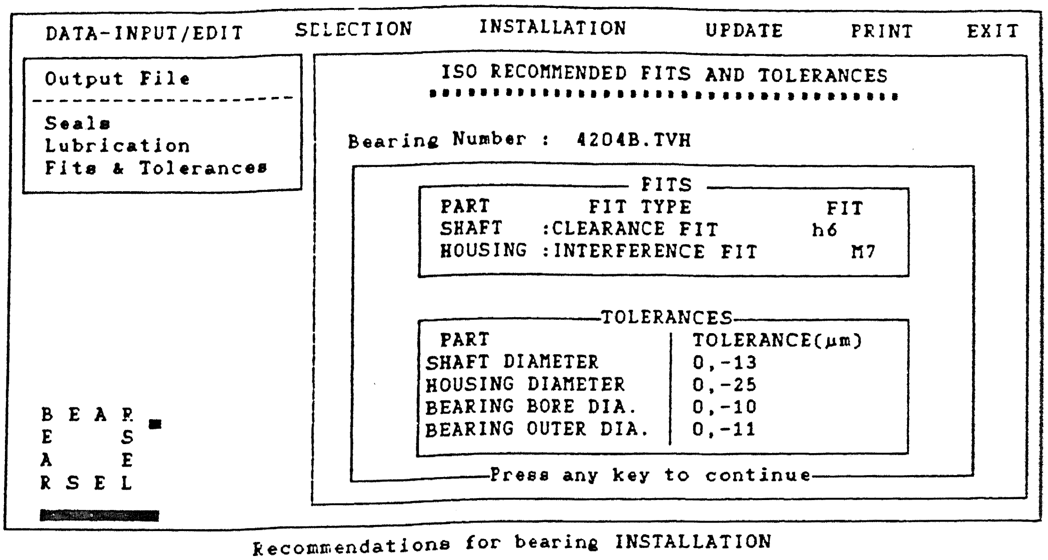


Figure 4.26: Screen printout of recommendations for fits for Example 4

Span	$a = 24\,m$
Weight of crane bridge	$G = 920\,kN$
Weight of travelling trolley	$K = 175\,kN$
Carrying capacity	$L = 245\,kN$
Travelling speed	$v = 2\,m/s$
Smallest distance between bearing and load with the trolley at extreame left/right position	$b = 1.8\,m$
Runwheel diameter	$900\,mm$
Hub width	$400\,mm$
Axle diameter	$140\,mm$
Bearing center distance	$250\,mm$

Fig. 4.27 shows the bearing load diagram. The loading depends on the position the travelling trolley so load fluctuates from a maximum value to a minimum value. T calculated parameters are as follows :

Radial load	$Maximum : 212\,kN; Minimum : 123\,kN$
Axial load	$36.5\,kN$
Sudden load	Negligible
Speed	$43 min^{-1}$

The input screen printout is shown in Fig. 4.28.

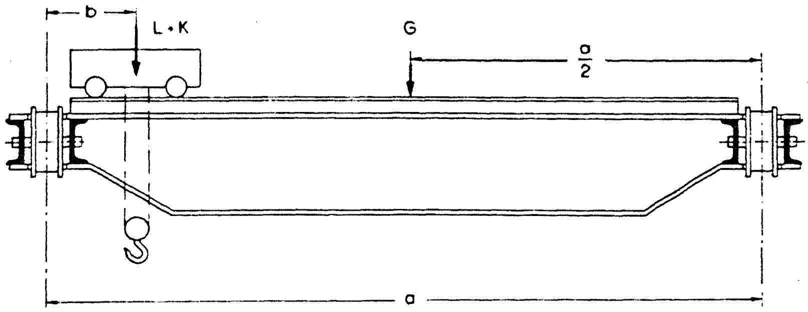


Figure 4.27: Load diagram for the steel mill crane

4.5.2 Outputs

The system suggests the spherical roller bearings 22328 C, as most suitable bearing. The screen printouts of various system outputs are shown in Figures 4.22 to 4.26 respectively.

```
                                      INPUT DATA DISPLAY
 SPEED              LOAD                                      RELIABILITY
(Constant)  **RADIAL**        **THRUST**                  RELIABILITY(%) : 90
            Fluctuating  (Constant)  DIRECTION
RPM VALUE   MAXIMUM      VALUE        Double              LIFE
   43         212000     36500                   OPERATING HRS :          12000
            MINIMUM                **SUDDEN**
              123000                                      TEMPARATURE
                                   Negligible     MAXIMUM TEMP. :          60
                                                  MINIMUM TEMP. :          30

                                                          DIMENSIONS
                                                 BORE DIA.: MAX. 150 MIN. 140
                                                 OUTER DIA: MAX.   0 MIN.   0
                                                 WIDTH    : MAX.   0 MIN.   0

                                      OPRATING CONDITIONS
RUNNING ACCURACY       :  1 RUNNING QUIETNESS: 1  0 -> UNDESIRABLE:
SELF ALIGN. CAPABILITY:  1 LOW FRICTION     : 1  1 -> USUAL      :
RADIAL RIGIDITY        :  1 MAINTENANCE EASE : 1  3 -> DESIRABLE  :
AXIAL RIGIDITY         :  1 COST             : 1  4 -> CRITICAL   :

                            PRESS ANY KEY TO CONTINUE
```

Figure 4.28: Screen printout of Input for Example 5

```
 DATA-INPUT/EDIT    SELECTION    INSTALLATION    UPDATE    PRINT    EXIT

 Input File                         SUITABLE BEARING TYPES
 --------------------
 Bearing Type              BEARNAME                 DBNAME   WEIGHTAGE
 --------------------
 BEARINGS BASED ON         DEEP GROOVE BALL(1)      DGBB1          29
 Load Ratings              ANGULAR CONT.BALL(2)     ACBB2          28
 + Speed (rpm)             ANGULAR CONT.BALL(3)     ACBB3          28
 + Dimensional limits      SPHERICAL ROLLER         SRB1           27
 --------------------      BARREL ROLLER            BRB            22
 Save                      SELF ALIGNING BALL       SABB           21
                           NEEDLE ROLLER(4)         NRB4           19

  B E A R               (More weightage value indicates higher priority)
  E     S
  A     E                    PLEASE SELECT ONE BEARING TYPE
  R S E L

keys and PRESS <Esc>
```

Figure 4.29: Screen printout of suitable bearing types for Example 5

FINALLY SELECTED SUITABLE BEARINGS

B_NUMBER	COMPANY	BORE_DIA	OUTER_DIA	WIDTH	C	CO	RPM_OIL	RPM_GR
22328C	SKF	140	300	102	980000	915000	1500	1100
23230C	SKF	150	270	96	815000	830000	1300	950
22330C	SKF	150	320	108	1120000	1040000	1400	1000

B_NUMBER : Bearing Number
C : Dynamic Load Rating(Newtons)
CO : Static Load Rating(Newtons)
RPM_* : Limiting Speeds(rpm)
MASS : Weight of bearing(g)
Linear Dimensions are in m.m.

PRESS [ESC] TO CONTINUE FURTHER
Use keys to see all BEARINGS and SPECIFICATIONS

Figure 4.30: Screen printout of finally selected bearings for Example 5

DATA-INPUT/EDIT SELECTION INSTALLATION UPDATE PRINT EXIT

Output File
Seals
Lubrication
Fits & Tolerances

SEALS & SHIELDS

Bearing Number : 22328C

BEARING AVAILABILITY

WITH (Integral)	STATUS
SINGLE SEAL	No
DOUBLE SEALS	No
SINGLE SHIELD	No
DOUBLE SHIELDS	No

NOTE : To select SEALS for UNSEALED BEARINGS
PRESS key F2

press any key to continue

B E A R
E S
A E
R S E L

Recommendations for bearing INSTALLATION

Figure 4.31: Screen printout of recommendations for seals for Example 5

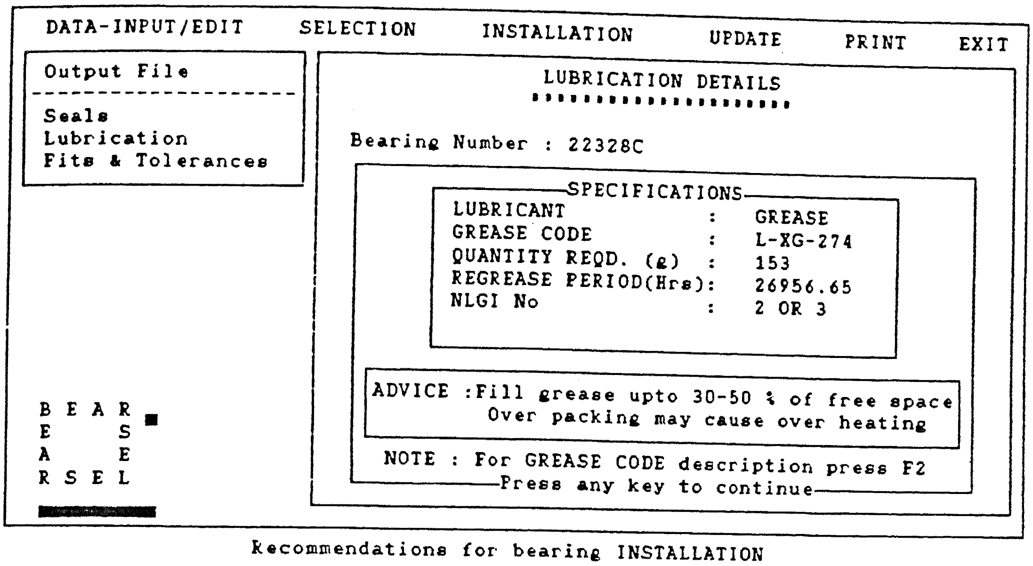


Figure 4.32: Screen printout of recommendations for lubrication for Example 5

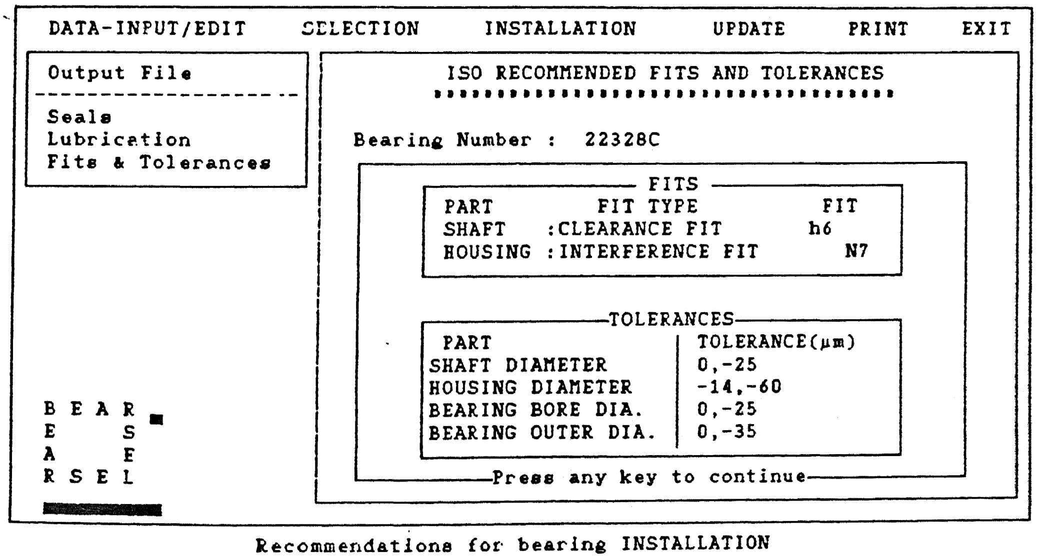


Figure 4.33: Screen printout of recommendations for fits for Example 5

Chapter 5

Conclusions and Suggestions for Future Work

5.1 conclusions

- In recent years, a number of researchers have tried to develope expert system/software which are useful in the selection of mechanical components. Computer aided selection is still a partially solved problem. This is probably because of the large degree of subjectivity involved in the process and lack of mathematical tools.

- In the present work an attempt has been made to develop a knowledge-based system, **BEARSEL**, for the selection of antifriction bearings alongwith the selection of sealing and lubrication methods, and fits and tolerances. This sytem has been developed for most of the bearing applications.

- Instead of restricting the user with a single result, several alternative bearings are suggested by the system and the user is enabled to select the most suitable one by using preference and peculiarities of the situation.

- The system is exhaustive and is easy to use. It uses the bearing databases generated by including bearings of leading manufacturers. The database can also be updated to include the new developements.

- It is hoped that BEARSEL will find acceptability among the designers and practising engineers of the industries, and will be a usefull module in the developement of a general computer aided design programme.

5.2 Scope for future work

In its present stage, BEARSEL performs well as a knowledge based system for the selection of antifriction bearings for general applications. However, BEARSEL is limited in a number of ways and there are several natural steps to take in order to improve the system.

More knowledge

More knowledge is needed to be incorporated to increase the viability of the system. More and more bearing data from different bearing manufacturers should be included. Bearing types like Spherical plain bearings, may also be included.

More functionality

More recommendations for expert issues like clearance, mounting, sealing and lubrication should be included.

Integration with other software

It is felt that integration with analysis programs and other software is best done through a modern system architecture where workstations and mainframes are connected through a local area network. The necessary programs might then be run on the workstations after necessary changes.

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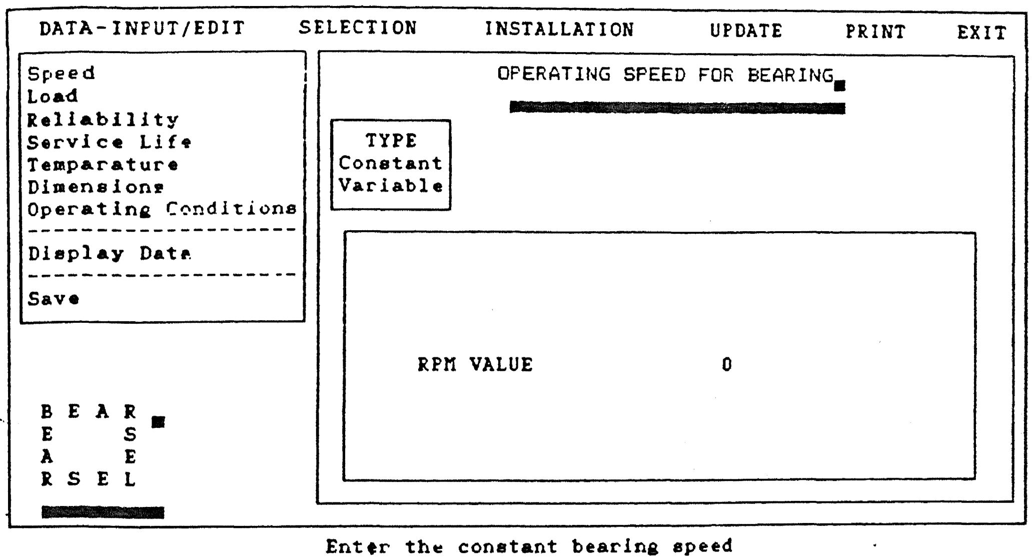
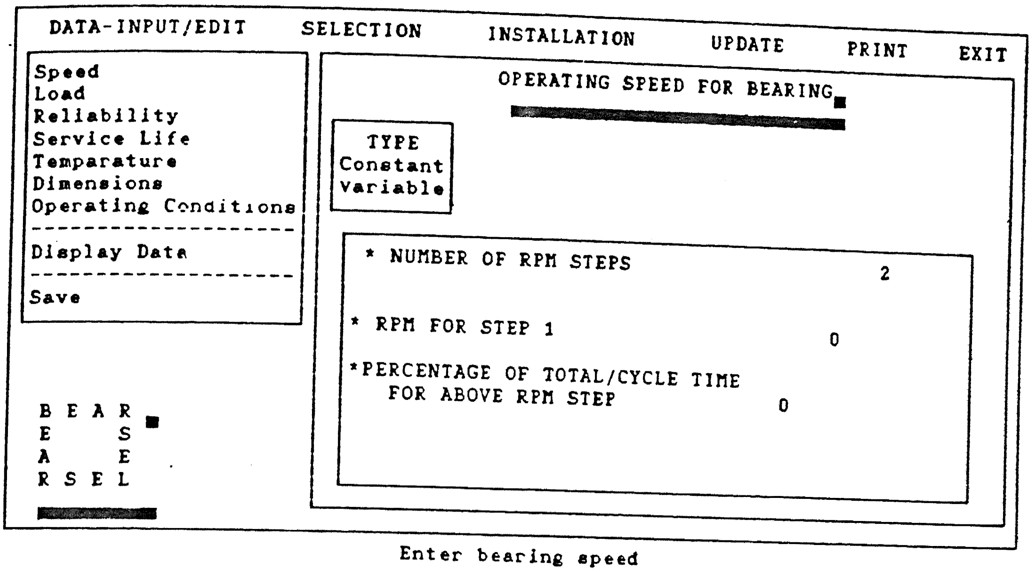
Appendix A

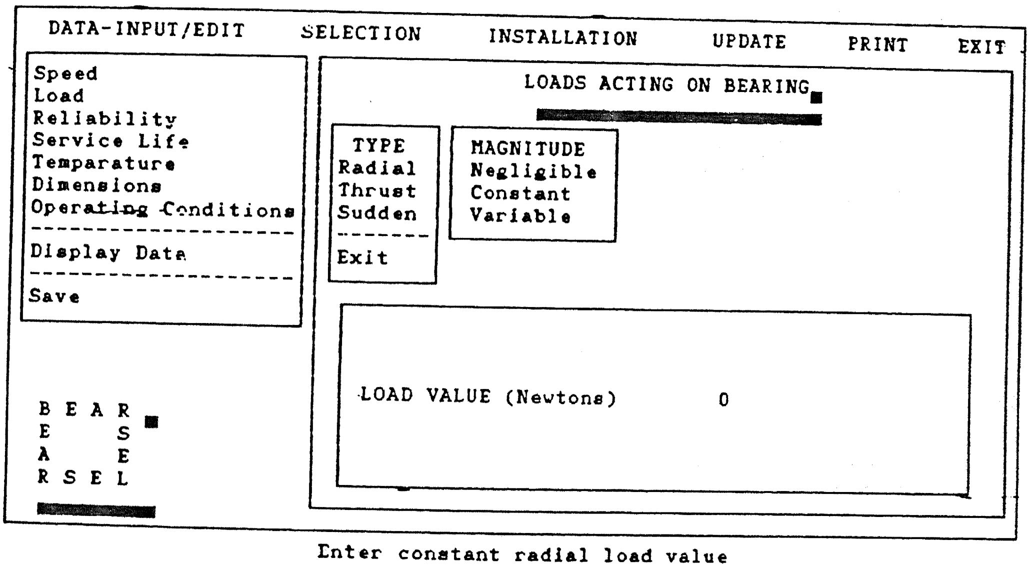
Screen Printouts of BEARSEL



Screen printout of input speed (constant) data



Screen printout of input speed (variable) data



Screen printout of input load (constant magnitude) data

```
DATA-INPUT/EDIT    SELECTION    INSTALLATION    UPDATE    PRINT    EXIT

Speed                          LOADS ACTING ON BEARING
Load
Reliability                    TYPE      MAGNITUDE    NATURE
Service Life                   Radial    Negligible   STEP Load (OR approximated)
Temparature                    Thrust    Constant     FLUCTUATING Load
Dimensions                     Sudden    Variable     1 CONSTANT + 1 ROTARY Loads
Operating Conditions           -------                OTHER Undefined Forms
--------------------           Exit
Display Data
--------------------
Save
                                 * NUMBER OF LOAD STEPS                    2

 B E A R                         * LOAD (Newtons) FOR STEP 1               0
 E     S
 A     E                        * PERCENTAGE OF TOTAL/CYCLE TIME
 R S E L                           FOR ABOVE LOAD STEP                     0

                      Enter the load value
```

Screen printout of input load (variable of step nature) data

```
DATA-INPUT/EDIT    SELECTION    INSTALLATION    UPDATE    PRINT    EXIT

Speed                          LOADS ACTING ON BEARING
Load
Reliability                    TYPE      MAGNITUDE    NATURE
Service Life                   Radial    Negligible   STEP Load (OR approximated)
Temparature                    Thrust    Constant     FLUCTUATING Load
Dimensions                     Sudden    Variable     1 CONSTANT + 1 ROTARY Loads
Operating Conditions           -------                OTHER Undefined Forms
--------------------           Exit
Display Data
--------------------
Save

                                * MAXIMUM LOAD (Newtons)        0

 B E A R                        * MINIMUM LOAD (Newtons)        0
 E     S
 A     E
 R S E L

                  Enter the maximum load value
```

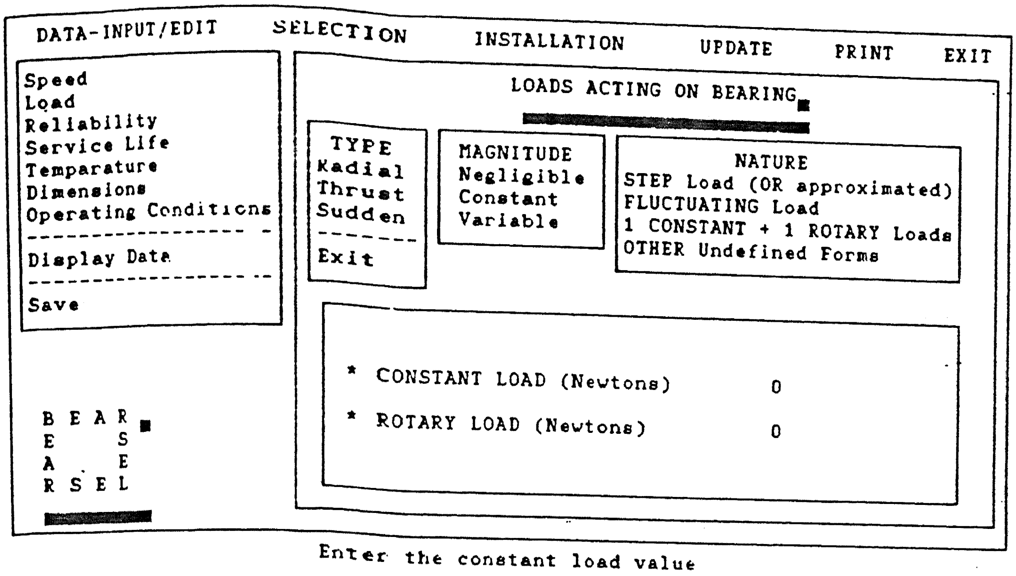
Screen printout of input load (variable of fluctuating nature) data

```
DATA-INPUT/EDIT     SELECTION     INSTALLATION     UPDATE     PRINT     EXIT

Speed                          LOADS ACTING ON BEARING
Load
Reliability             TYPE      MAGNITUDE     NATURE
Service Life            Radial    Negligible    STEP Load (OR approximated)
Temparature             Thrust    Constant      FLUCTUATING Load
Dimensions              Sudden    Variable      1 CONSTANT + 1 ROTARY Loads
Operating Conditions    -------                 OTHER Undefined Forms
--------------------    Exit
Display Date
--------------------
Save

                          * CONSTANT LOAD (Newtons)        0
B E A R
E     S                   * ROTARY LOAD (Newtons)          0
A     E
R S E L

                   Enter the constant load value
```

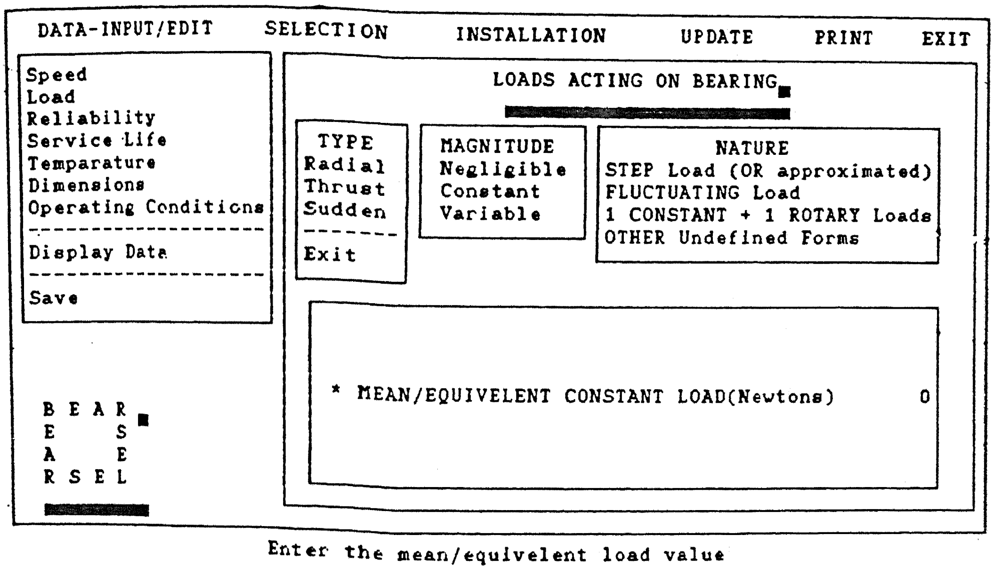
Screen printout of input load (variable of stationary cum rotary nature) data

```
DATA-INPUT/EDIT     SELECTION     INSTALLATION     UPDATE     PRINT     EXIT

Speed                          LOADS ACTING ON BEARING
Load
Reliability             TYPE      MAGNITUDE     NATURE
Service Life            Radial    Negligible    STEP Load (OR approximated)
Temparature             Thrust    Constant      FLUCTUATING Load
Dimensions              Sudden    Variable      1 CONSTANT + 1 ROTARY Loads
Operating Conditions    -------                 OTHER Undefined Forms
--------------------    Exit
Display Date
--------------------
Save

                          * MEAN/EQUIVELENT CONSTANT LOAD(Newtons)      0
B E A R
E     S
A     E
R S E L

                   Enter the mean/equivelent load value
```

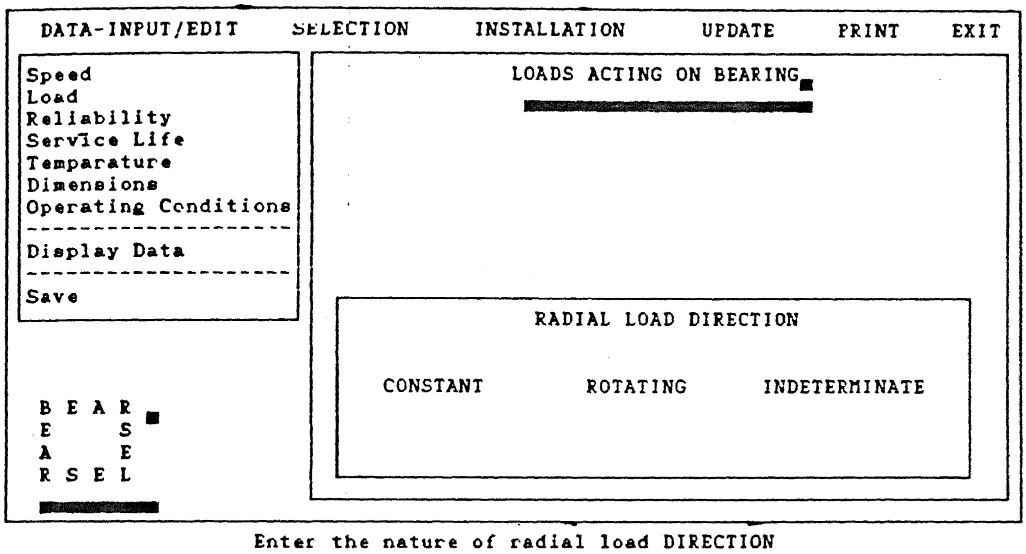
Screen printout of input load (variable of undefined forms) data



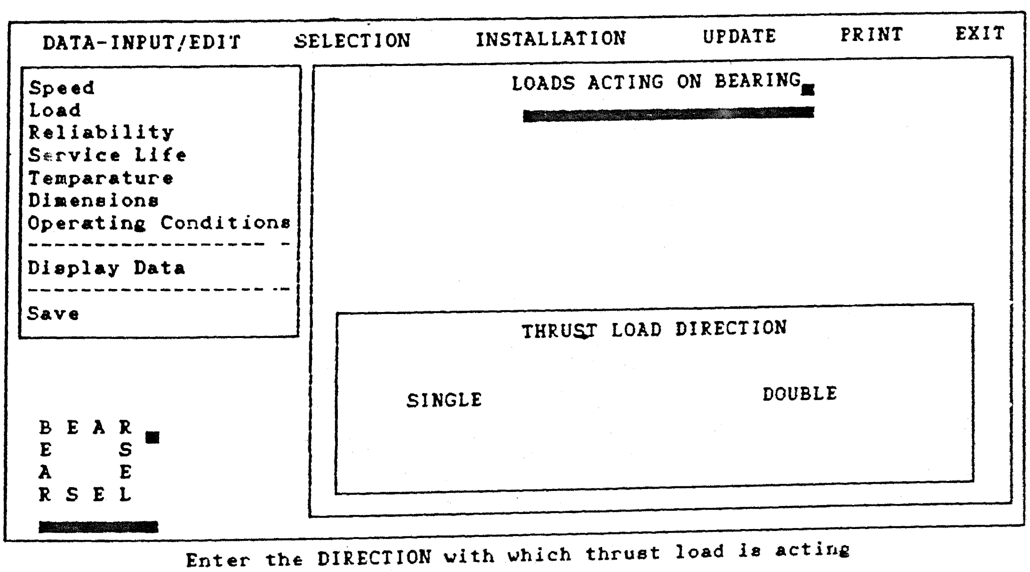
Screen printout of input load (variable of stationary cum rotary nature) data



Screen printout of input load (variable of undefined forms) data



Screen printout of input load (radial load direction) data



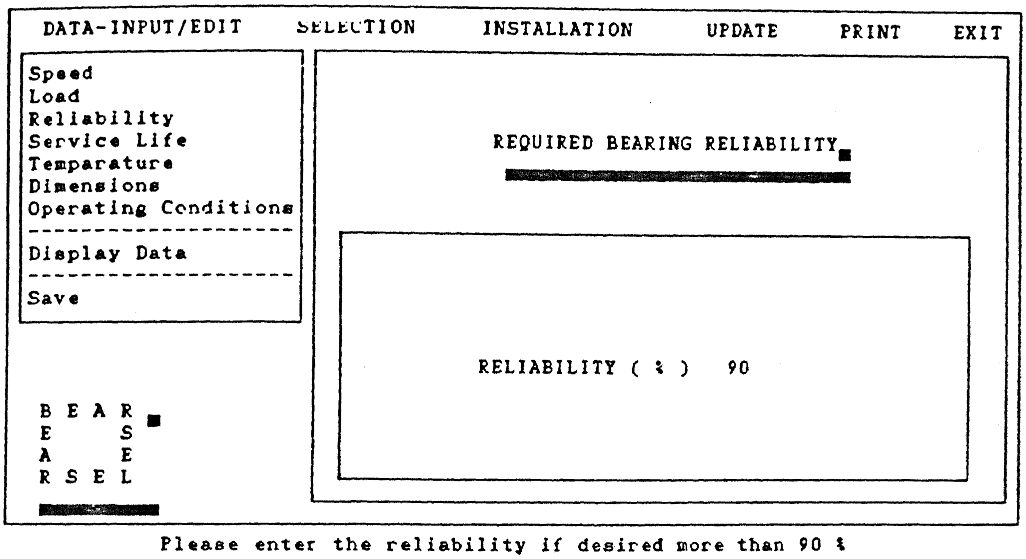
Screen printout of input load (thrust load direction) data

```
DATA-INPUT/EDIT   SELECTION   INSTALLATION   UPDATE   PRINT   EXIT

Speed                          LOADS ACTING ON BEARING
Load
Reliability                TYPE       Negligible
Service Life               Radial     With LIGHT shock
Temparature                Thrust     With MEDIUM shock
Dimensions                 Sudden     With HEAVY shock
Operating Conditions       -------    ------------------
--------------------       Exit       Help
Display Data
--------------------
Save

B E A R
E     S
A     E
R S E L

Select sudden LOAD TYPE or HELP to select for different application
```

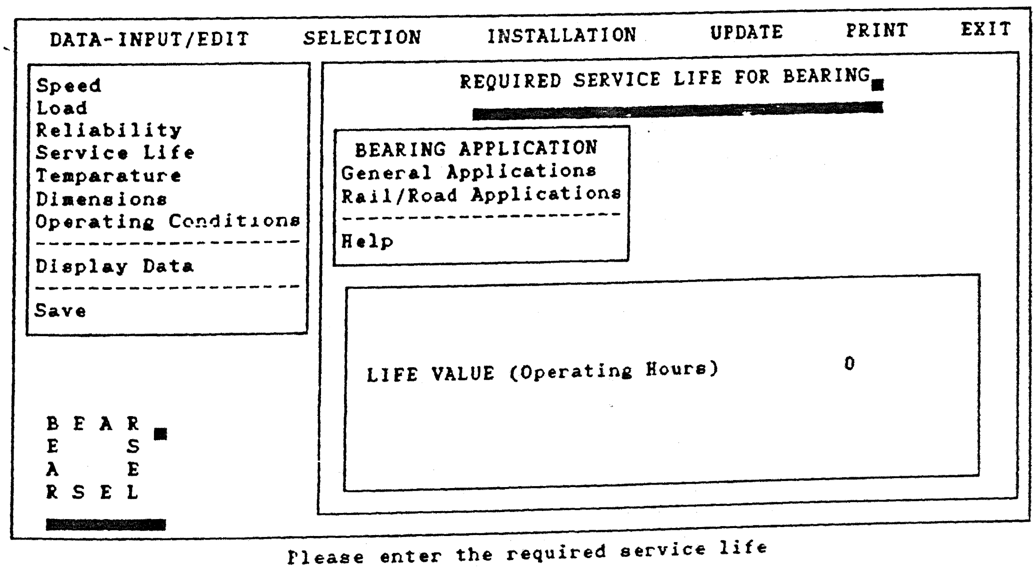
Screen printout of input load (sudden) data

```
DATA-INPUT/EDIT   SELECTION   INSTALLATION   UPDATE   PRINT   EXIT

Speed                          LOADS ACTING ON BEARING
Load
Reliability           USE                                         DUTY_TYPE
Service Life
Temparature           -----------------------------------------   ---------
Dimensions            GENERAL PUPPOSE CHAIN AND GEAR DRIVES       ALMOST
Operating Conditions  COAL, SAND AND ORE CONVEYORS                  NO
--------------------  ROTARY COMPRESSORS                          SUDDEN
Display Data          ELECTRIC MOTORS                             LOAD
--------------------  (AUTO PINIONS, FRONT WHEELS, REAR WHEELS AND
Save                  TRANSMISSIONS WITH INDEPEDENT SUSPENSION)
                      FARM MACHINARIES ; ENGINES
                      HOUSEHOLD APPLIANCES
                      -----------------------------------------   ---------
B E A R               FANS ; CENTRIFUGAL BLOWERS MIXERS           LIGHT
E     S               CONTINUOUSLY OPRATED CRANES                 SHOCK
A     E               BELT TENSION DEVICES                        SERVICE
R S E L               APPLICATION WITH DEADWEIGHT AS PRINCIPAL LOAD
                      GROUND GEARS

Press <Esc> to EXIT Help
```

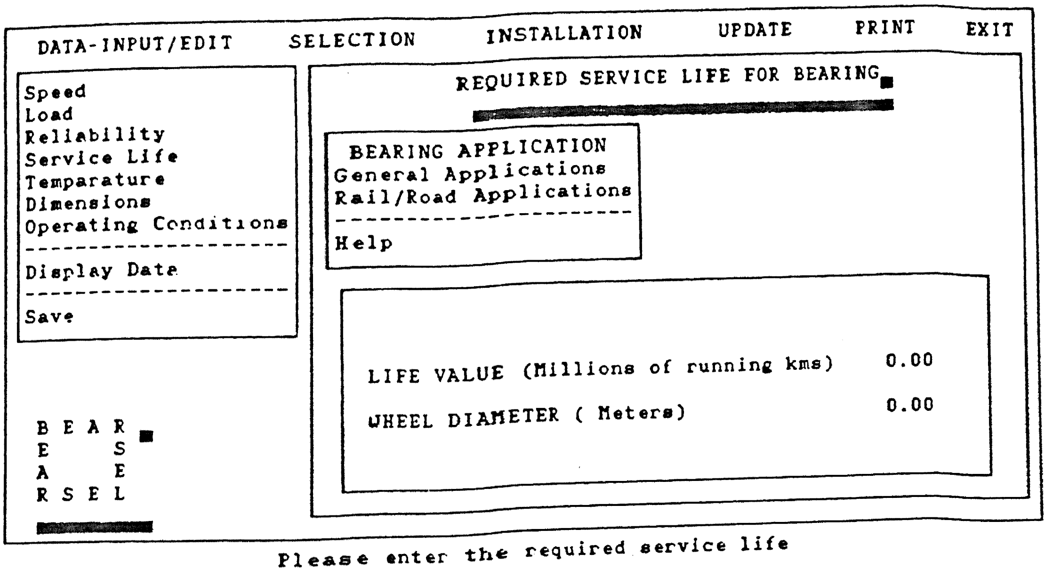
Screen printout of help display for sudden load



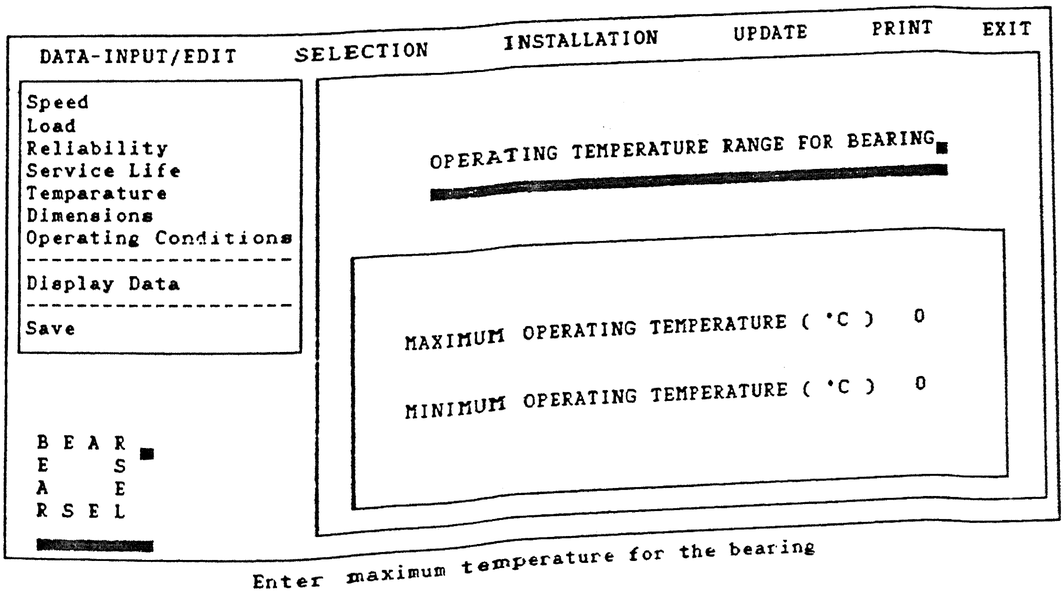
Screen printout of input reliability data



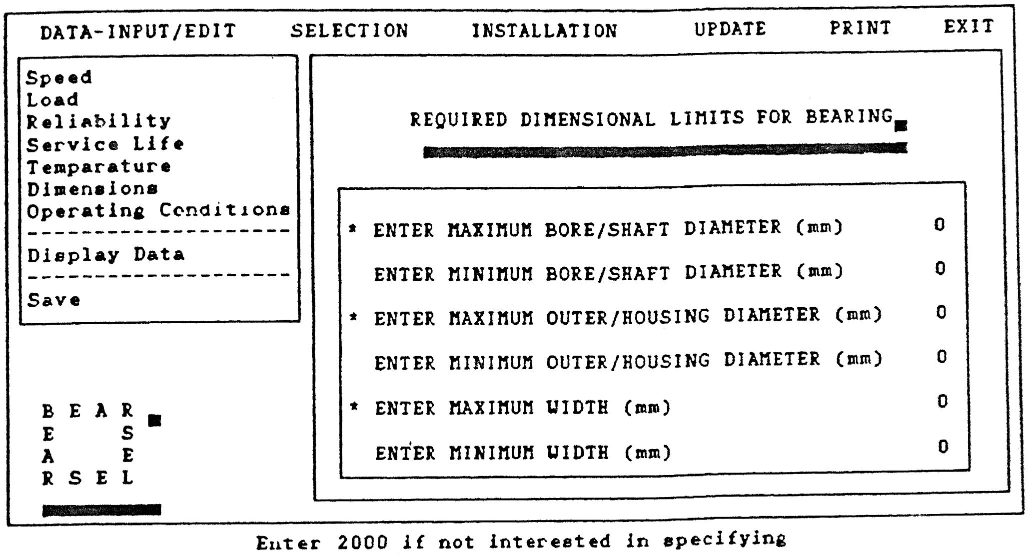
Screen printout of input service life (general applications) data



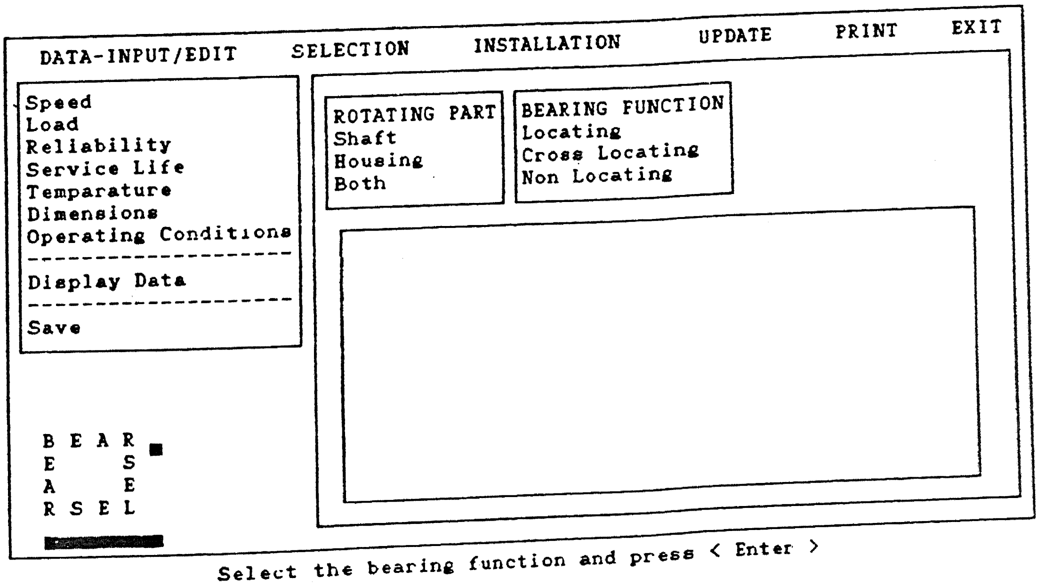
Screen printout of input service life (rail/road applications) data



Screen printout of input operating temperature data



Screen printout of input dimensions data



Screen printout of input operating conditions

```
 DATA-INPUT/EDIT     SELECTION      INSTALLATION      UPDATE      PRINT     EXIT

 Speed                          PLEASE ENTER THE DESIRED LEVEL
 Load                            FOR ALL OPERATING CONDITIONS
 Reliability
 Service Life
 Temparature
 Dimensions
 Operating Conditions      OPERATING CONDITIONS          DESIRED LEVEL
 --------------------
 Display Data               Running Accuracy
 --------------------       Self Alignment Capability
 Save                       Radial Rigidity
                            Axial Rigidity                  Critical
                            Running Quietness               Important
                            Low Friction                      Usual
                            Maintenance                    Undesirable
  B E A R                   Cost
  E     S                   EXIT TO MAIN MENU
  A     E
  R S E L

         Select desired level of OPERATING CONDITION and press < Enter >
```

Screen printout of input operating conditions (contd ...)

```
                              INPUT DATA DISPLAY

                                                          IPNAME

                                                          CURRENT
                                                          EX1
                                                          EX2
                                                          EX3
   SELECT THE INPUT FILE FOR DATA DISPLAY :               EX4
                                                          EX5
                                                          EX6
                                                          EX7
                                                          EX8
                                                          EX9
                                                          EX10

   The CURRENT is the name of INPUT FILE having currently entered data

          Select the input file name (IPNAME) and press < Esc >
```

Screen printout of input data display (input file selection)

```
                              INPUT DATA DISPLAY
 SPEED        |                 LOAD                    |       RELIABILITY
(Constant)    | **RADIAL**  |       **THRUST**          |  RELIABILITY(%) : 90
              | (Constant)  | (Constant)| DIRECTION     |
RPM VALUE     |  VALUE      |  VALUE    |  Single       |          LIFE
   3000       |   2120      |   6000    |               | OPERATING HRS :      40000
              |             |           | **SUDDEN**    |
              |             |           |               |
              |             |           |  Negligible   |       TEMPARATURE
              |             |           |               |  MAXIMUM TEMP. :        70
              |             |           |               |  MINIMUM TEMP. :        30
              |             |           |               |
              |             |           |               |       DIMENSIONS
              |             |           |               | BORE DIA.: MAX.   80 MIN.  70
              |             |           |               | OUTER DIA: MAX.    0 MIN.   0
              |             |           |               | WIDTH   :  MAX.    0 MIN.   0

                              OPRATING CONDITIONS
RUNNING ACCURACY       :  4|RUNNING QUIETNESS: 1|0 -> UNDESIRABLE:
SELF ALIGN. CAPABILITY:  1|LOW FRICTION     : 3|1 -> USUAL       :
RADIAL RIGIDITY        :  3|MAINTENANCE EASE : 1|3 -> DESIRABLE   :
AXIAL RIGIDITY         :  3|COST             : 1|4 -> CRITICAL    :

                          PRESS ANY KEY TO CONTINUE
```

Screen printout of input data display (data display)

```
 DATA-INPUT/EDIT    SELECTION    INSTALLATION     UPDATE     PRINT    EXIT

 Input File
 --------------------          INPUT FILE FOR BEARING SELECTION
 Bearing Type
 --------------------
 BEARINGS BASED ON                                              IPNAME
 Load Ratings
 + Speed (rpm)                                                  CURRENT
 + Dimensional limits                                           EX1
 --------------------                                           EX2
 Save                   SELECT INPUT FILE FOR BEARING SELECTION: EX3
                                                                EX4
                                                                EX5
                                                                EX6
                                                                EX7
  B E A R                                                       EX8
  E     S               ( CURRENT is the input file containing  EX9
  A     E                 currently entered input data)
  R S E L

keys to see all names)
```

Screen printout of input file selection for bearing selection

DATA-INPUT/EDIT SELECTION INSTALLATION UPDATE PRINT EXIT

Input File

Bearing Type

BEARINGS BASED ON
Load Ratings
+ Speed (rpm)
+ Dimensional limits

Save

SUITABLE BEARING TYPES

BEARNAME	DBNAME	WEIGHTAGE
ANGULAR CONT.BALL(2)	ACBB2	58
ANGULAR CONT.BALL(3)	ACBB3	58
DEEP GROOVE BALL(1)	DGBB1	57

(More weightage value indicates higher priority)

PLEASE SELECT ONE BEARING TYPE

B E A R
E   S
A   E
R S E L

keys and PRESS <Esc>

Screen printout of suitable bearing types display

SUITABLE BEARINGS ACCORDING TO LOAD RATINGS

B_NUMBER	COMPANY	BORE_DIA	OUTER_DIA	WIDTH	C	CO	RPM_OIL	RIM_GRES	M
7218BG	SKF	90	160	60	132000	150000	3400	2400	
7314BG	SKF	70	150	70	143000	143000	3800	2800	
7219BG	SKF	95	170	64	150000	173000	3200	2200	
7315BG	SKF	75	160	74	153000	160000	3600	2600	
7321B	SKF	105	225	49	156000	163000	3000	2200	
7220BG	SKF	100	180	68	163000	183000	3000	2000	
7316BG	SKF	80	170	78	166000	180000	3400	2400	
7317BG	SKF	85	180	82	180000	200000	3200	2200	
7222BG	SKF	110	200	76	190000	228000	2800	1900	

B_NUMBER : Bearing Number
C : Dynamic Load Rating(Newtons)
CO : Static Load Rating(Newtons)
RPM_* : Limiting Speeds(rpm)
MASS : Weight of bearing(g)
Linear Dimensions are in m.m.

PRESS [ESC] TO CONTINUE FURTHER

Use keys to see all BEARINGS and SPECIFICATIONS

Screen printout of display of suitable bearings (based on load ratings)

SUITABLE BEARINGS ACCORDING TO LOAD RATING & RPM

B_NUMBER	COMPANY	BORE_DIA	OUTER_DIA	WIDTH	C	CO	RPM_OIL	RPM_GRES	M
7314BG	SKF	70	150	70	143000	143000	3800	2800	
7315BG	SKF	75	160	74	153000	160000	3600	2600	
7316BG	SKF	80	170	78	166000	180000	3400	2400	
7317BG	SKF	85	180	82	180000	200000	3200	2200	
7218BG	SKF	90	160	60	132000	150000	3400	2400	
7318BG	SKF	90	190	86	193000	224000	3000	2000	1
7219BG	SKF	95	170	64	150000	173000	3200	2200	
7220BG	SKF	100	180	68	163000	183000	3000	2000	
7321B	SKF	105	225	49	156000	163000	3000	2200	

B_NUMBER : Bearing Number
C : Dynamic Load Rating(Newtons)
CO : Static Load Rating(Newtons)
RPM_* : Limiting Speeds(rpm)
MASS : Weight of bearing(g)
Linear Dimensions are in m.m.

PRESS [ESC] TO CONTINUE FURTHER
Use keys to see all BEARINGS and SPECIFICATIONS

Screen printout of display of suitable bearings (load ratings + speed)

FINALLY SELECTED SUITABLE BEARINGS

B_NUMBER	COMPANY	BORE_DIA	OUTER_DIA	WIDTH	C	CO	RPM_OIL	RPM_GRES	M
7314BG	SKF	70	150	70	143000	143000	3800	2800	
7315BG	SKF	75	160	74	153000	160000	3600	2600	
7316BG	SKF	80	170	78	166000	180000	3400	2400	

B_NUMBER : Bearing Number
C : Dynamic Load Rating(Newtons)
CO : Static Load Rating(Newtons)
RPM_* : Limiting Speeds(rpm)
MASS : Weight of bearing(g)
Linear Dimensions are in m.m.

PRESS [ESC] TO CONTINUE FURTHER
Use keys to see all BEARINGS and SPECIFICATIONS

Screen printout of display of suitable bearings (finally selected)

DATA-INPUT/EDIT SELECTION INSTALLATION UPDATE PRINT EXIT

Output File

Seals
Lubrication
Fits & Tolerances

BEARING INSTALLATION

SELECT THE OUTPUT FILE :

OPNAME	IPNAME	BTNAME
CURRENT	EX4	ACBB2
EX1_1	EX1	DGBB1
EX2_1	EX2	CRB1
EX3_1	EX3	ACBB2
EX3_2	EX3	CRB3
EX4_1	EX4	ACBB2
EX5_1	EX5	DGBB1
EX6_1	EX6	SRB1
EX7_1	EX7	SRB1

BEAR
E S
A E
RSEL

Select output file name (OPNAME) using keys & Press <Esc>

Screen printout of output file selection for bearing installation

DATA-INPUT/EDIT SELECTION INSTALLATION UPDATE PRINT EXIT

Output File

Seals
Lubrication
Fits & Tolerances

SEALS & SHIELDS

Bearing Number : 7314BG

BEARING AVAILABILITY

	STATUS
WITH (Integral)	
SINGLE SEAL	No
DOUBLE SEALS	No
SINGLE SHIELD	No
DOUBLE SHIELDS	No

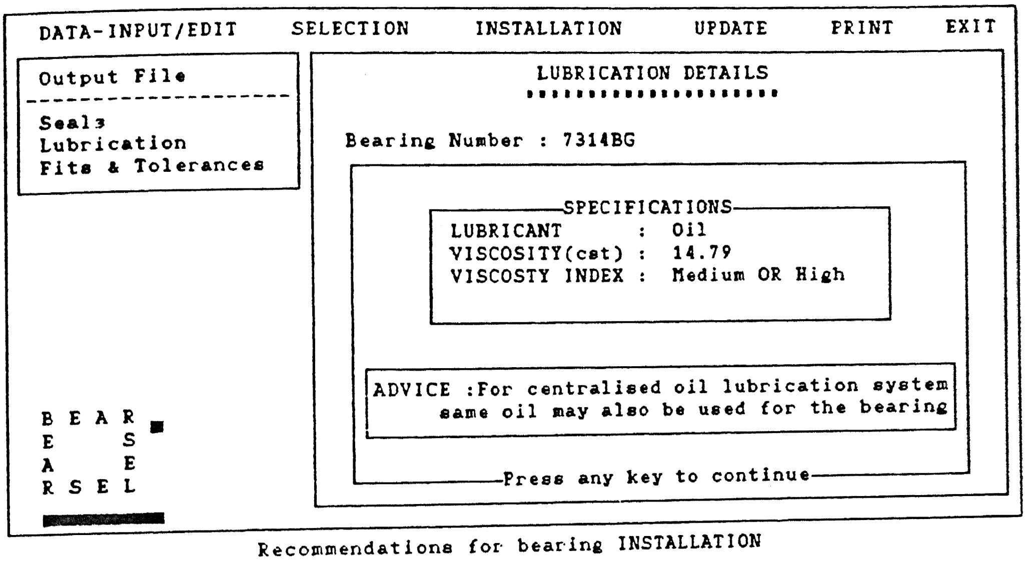
NOTE : To select SEALS for UNSEALED BEARINGS
PRESS key F2

press any key to continue

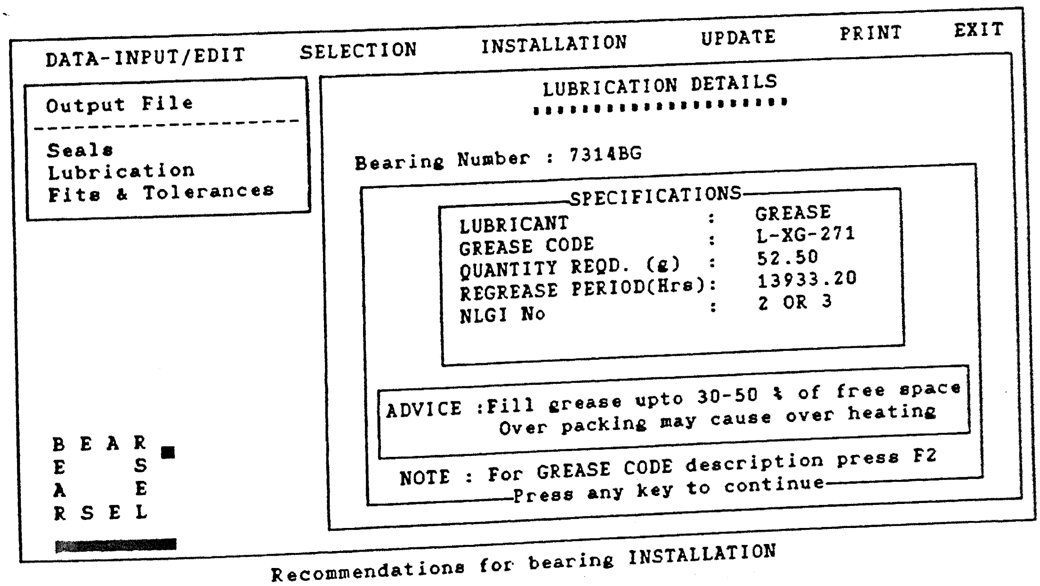
BEAR
E S
A E
RSEL

Recommendations for bearing INSTALLATION

Screen printout of recommendations for seals for bearing installation



Screen printout of recommendations for bearing lubrication (oil)



Screen printout of recommendations for bearing lubrication (grease)

```
DATA-INPUT/EDIT   SELECTION   INSTALLATION   UPDATE   PRINT   EXIT

Output File                 ISO RECOMMENDED FITS AND TOLERANCES
--------------------
Seals                     Bearing Number :  7314BG
Lubrication
Fits & Tolerances                      FITS
                          PART          FIT TYPE            FIT
                          SHAFT    :INTERFERENCE FIT         j6
                          HOUSING  :CLEARANCE FIT          H7

                                    TOLERANCES
                          PART                   TOLERANCE(µm)
                          SHAFT DIAMETER         +12,-7
                          HOUSING DIAMETER       0,+40
B E A R                   BEARING BORE DIA.      0,-15
E     S                   BEARING OUTER DIA.     0,-18
A     E
R S E L                     Press any key to continue

              Recommendations for bearing INSTALLATION
```

Screen printout of recommendations for ISO fits and tolerances

```
DATA-INPUT/EDIT   SELECTION   INSTALLATION   UPDATE   PRINT   EXIT

DATA-BASE
Add
Edit
View
Delete





B E A R
E     S
A     E
R S E L

              UPDATE bearing data-bases
```

Screen printout of update bearing databases

UPDATE BEARING DATA-BASE

SELECT THE BEARING DATABASE TO Add THE DATA

BEARNAME
ANGULAR CONT.BALL(1)
ANGULAR CONT.BALL(2)
ANGULAR CONT.BALL(3)
ANGU.CONT.THR.BALL(S.D.)
ANGU.CONT.THR.BALL(D.D.)
BARREL ROLLER
CLYNDRICAL ROLLER(1)
CLYNDRICAL ROLLER(3)
CLYNDRICAL ROLLER(5)
CLYNDR.ROLL.(DOUB.ROW)
CLYNDR.ROLL.THRUST
DEEP GROOVE BALL(1)
DEEP GROOVE BALL(2)
FOUR POINT CONT.BALL
MEGNETO
NEEDLE ROLLER(1)

Select the DATA-BASE name (BEARNAME) & Press <Esc> to continue

Screen printout of update bearing databases (database selection)

UPDATE BEARING DATA-BASE

TYPE	B_NUMBER	COMPANY	BORE_DIA	OUTER_DIA	WIDTH	C	CO	RPM_GRES	RPM_O
	123456	SKF							

(Use keys to SCROLL the DATA-BASE table)

B_NUMBER : Bearing Number
C : Dynamic Load Rating(Newtons)
CO : Static Load Rating(Newtons)
RPM_* : Limiting Speeds(rpm)
Linear Dimensions are in m.m.

Press F2 for ATTRIBUTE DESCRIPTION

Please enter all BEARING ATTRIBUTES & Press <Esc> to continue

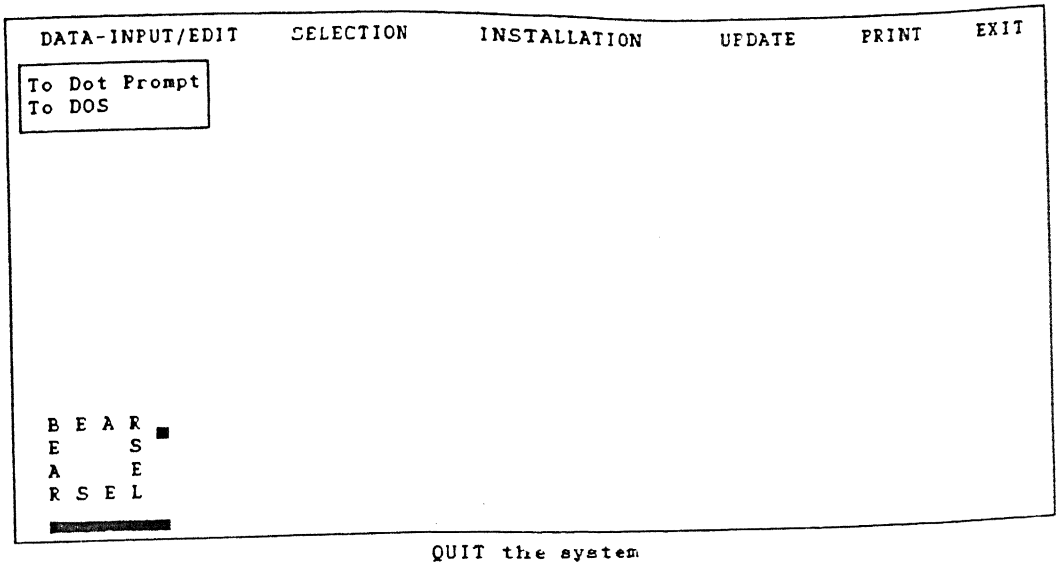
Screen printout of update bearing databases (data entry)

```
DATA-INPUT/EDIT    SELECTION    INSTALLATION    UPDATE    PRINT    EXIT

Database
Input Data
Bearings Selected
Others
                                                  BEARNAME

                                                  ANGULAR CONT.BALL(1)
                                                  ANGULAR CONT.BALL(2)
                                                  ANGULAR CONT.BALL(3)
                                                  ANGU.CONT.THR.BALL(S.D.)
                                                  ANGU.CONT.THR.BALL(D.D.)
                                                  BARREL ROLLER
             SELECT THE BEARING                   CLYNDRICAL ROLLER(1)
             DATABASE TO PRINT :                  CLYNDRICAL ROLLER(3)
                                                  CLYNDRICAL ROLLER(5)
                                                  CLYNDR.ROLL.(DOUB.ROW)
                                                  CLYNDR.ROLL.THRUST
                                                  DEEP GROOVE BALL(1)
B E A R                                           DEEP GROOVE BALL(2)
E     S
A     E
R S E L

   Select the bearing data-base name(BEARNAME) with  keys & Press <Esc>
```

Screen printout of printing bearing databases

```
                          INPUT-DATA                    File Name:   EX3
------------------------------------------------------------------------------
 SPEED : Constant
RPM VALUE :    1300
------------------------------------------------------------------------------
                                                  # OF STEPS :2
 RADIAL LOAD : Step Load    ;
LOAD VALUES :      6100,      6575,
% OF CYCLE :        50,        50,
 THRUST LOAD : Constant ;
LOAD VALUE :       800
THRUST LOAD DIRECTION :Double
SUDDEN LOAD :Medium Shock
------------------------------------------------------------------------------
RELIABILITY(%) : 90                                 ; WHEEL DIA.(m) :0.52
LIFE :          RUNNING KMS(million) :3.00
TEMPARATURE :
MAXIMUM TEMP. : 90
MINIMUM TEMP. : 30
DIMENSIONS :            MAXIMUM              MINIMUM
BORE DIA.:                95                    90
OUTER DIA.:                0                     0
WIDTH   :                  0                     0
------------------------------------------------------------------------------
OPRATING CONDITIONS :                     ;   RUNNING QUIETNESS:1
RUNNING ACCURACY          :4              ;   COST              :4
SELF ALIGN. CAPABILITY:1                  ;   MAINTENANCE EASE  :1
RADIAL RIGIDITY           :3              ;   LOW FRICTION      :1
AXIAL RIGIDITY            :1
(0 -> Undesirable ; 1 -> USUAL   ; 3 -> DESIRABLE  ; 4 -> CRITICAL)
------------------------------------------------------------------------------
```

Screen printout of printing input data



Screen printout of exit module

Appendix B

BEARSEL System Details

B.1 System Summary

```
--------------------------------------------
This system has:
  5008 lines of code
    56 program files
     1 procedure files
    54 procedures and functions
    61 databases
     4 index files
     1 report forms
     0 format files
     0 label forms
     0 binary files
     0 memory variable files
     0 other files
   427 cross-referenced tokens

--------------------------------------------
```

```
|         |         |         INPUT.DBF (database)
|         |         |         TEMPDATA.DBF (database)
|         |         └─────────BIPBIP      (procedure in PROCED2.PRG)
|         └─────────IDSAVE.PRG
|                   |         INPUT.DBF (database)
|                   ├─────────BIPBIP      (procedure in PROCED2.PRG)
|                   └─────────SAVED      (procedure in IDSAVE.PRG)
|                             |         INPUT.DBF (database)
|                             |         TEMPDATA.DBF (database)
|                             |         OUTPUT.DBF (database)
|                             |         TEMPSEL.DBF (database)
|                             |         &FNAME (database)
|                             ├─────────BIPBIP      (procedure in PROCED2.PRG)
|                             └─────────SAVED      (procedure in IDSAVE.PRG)
|                                       |         INPUT.DBF (database)
|                                       |         TEMPDATA.DBF (database)
|                                       |         OUTPUT.DBF (database)
|                                       |         TEMPSEL.DBF (database)
|                                       |         &FNAME (database)
*** Truncating tree for recursive call to SAVED
├─────────MAIN2      (procedure in MAIN.PRG)
|         ├─────────SELECT1.PRG
|         |         |         INPUT.DBF (database)
|         |         |         TMPSEL.DBF (database)
|         |         |         OUTPUT.DBF (database)
|         |         ├─────────BIPBIP      (procedure in PROCED2.PRG)
|         |         ├─────────ONLYRL1.PRG
|         |         |         |         SELECT.DBF (database)
|         |         |         |         FINAL.DBF (database)
|         |         |         |         TEMPORL.DBF (database)
|         |         |         |         TEMPLOC.DBF (database)
|         |         |         |         TSORT6.DBF (database)
|         |         |         ├─────────ERROR1      (procedure in PROCED2.PRG)
|         |         |         |         └─────────BIPBIP      (procedure in PROCED2.PRG)
|         |         |         ├─────────LOCAT_1      (procedure in PROCED2.PRG)
|         |         |         |                   TEMPLOC.DBF (database)
|         |         |         └─────────SORT_1      (procedure in PROCED2.PRG)
|         |         |                             TSOTR1.DBF (database)
|         |         |                             TSORT1.DBF (database)
|         |         |                             TEMPLOC.DBF (database)
|         |         |                             TSOTR2.DBF (database)
|         |         |                             TSORT2.DBF (database)
|         |         |                             TSORT3.DBF (database)
|         |         |                             TSORT4.DBF (database)
|         |         |                             TSORT5.DBF (database)
|         |         |                             TSORT6.DBF (database)
|         |         ├─────────ONLYTL1.PRG
|         |         |         |         SELECT.DBF (database)
|         |         |         |         FINAL.DBF (database)
|         |         |         |         TEMPTL.DBF (database)
|         |         |         |         TEMPTL1.DBF (database)
|         |         |         |         TSORT6.DBF (database)
|         |         |         ├─────────ERROR1      (procedure in PROCED2.PRG)
|         |         |         |         └─────────BIPBIP      (procedure in PROCED2.PRG)
|         |         |         └─────────SORT_1      (procedure in PROCED2.PRG)
```

```
│    │    │              TSOTR1.DBF (database)
│    │    │              TSORT1.DBF (database)
│    │    │              TEMPLOC.DBF (database)
│    │    │              TSOTR2.DBF (database)
│    │    │              TSORT2.DBF (database)
│    │    │              TSORT3.DBF (database)
│    │    │              TSORT4.DBF (database)
│    │    │              TSORT5.DBF (database)
│    │    │              TSORT6.DBF (database)
│    │    └────COMLOAD1.PRG
│    │         │    SELECT.DBF (database)
│    │         │    FINAL.DBF (database)
│    │         │    TEMPCL.DBF (database)
│    │         │    TEMPLOC.DBF (database)
│    │         │    TSORT6.DBF (database)
│    │         ├────ERROR1     (procedure in PROCED2.PRG)
│    │         │    └────BIPBIP     (procedure in PROCED2.PRG)
│    │         ├────LOCAT_1     (procedure in PROCED2.PRG)
│    │         │         TEMPLOC.DBF (database)
│    │         └────SORT_1     (procedure in PROCED2.PRG)
│    │                   TSOTR1.DBF (database)
│    │                   TSORT1.DBF (database)
│    │                   TEMPLOC.DBF (database)
│    │                   TSOTR2.DBF (database)
│    │                   TSORT2.DBF (database)
│    │                   TSORT3.DBF (database)
│    │                   TSORT4.DBF (database)
│    │                   TSORT5.DBF (database)
│    │                   TSORT6.DBF (database)
│    ├────FINAL_1     (procedure in PROCED2.PRG)
│    │    │    FINAL.DBF (database)
│    │    │    OUTPUT.DBF (database)
│    │    │    TEMPCAP.DBF (database)
│    │    │    TEMPRPM.DBF (database)
│    │    ├────BIPBIP     (procedure in PROCED2.PRG)
│    │    └────ERROR1     (procedure in PROCED2.PRG)
│    │         └────BIPBIP     (procedure in PROCED2.PRG)
│    ├────SELECT2.PRG
│    │    ├────&NAME
│    │    └────BIPBIP     (procedure in PROCED2.PRG)
│    ├────SELECT3.PRG
│    │    ├────RPMSORT     (procedure in PROCED2.PRG)
│    │    │    │    TEMPCAP.DBF (database)
│    │    │    │    TEMPRPM.DBF (database)
│    │    │    │    TEMPSEL.DBF (database)
│    │    │    ├────BIPBIP     (procedure in PROCED2.PRG)
│    │    │    └────SHOWCAP     (procedure in PROCED2.PRG)
│    │    └────BIPBIP     (procedure in PROCED2.PRG)
│    ├────SELECT4.PRG
│    │    ├────DIMSORT     (procedure in PROCED2.PRG)
│    │    │    │    TEMPRPM.DBF (database)
│    │    │    │    TEMPBD.DBF (database)
│    │    │    │    TEMPOD.DBF (database)
│    │    │    │    TEMPW.DBF (database)
│    │    │    │    TEMPSEL.DBF (database)
│    │    │    │
```

```
|    |    |    |------ERROR3      (procedure in PROCED2.PRG)
|    |    |    |    └------BIPBIP      (procedure in PROCED2.PRG)
|    |    |    |------ERROR4      (procedure in PROCED2.PRG)
|    |    |    |    |------ERROR5      (procedure in PROCED2.PRG)
|    |    |    |    └------BIPBIP      (procedure in PROCED2.PRG)
|    |    |    └------SHOWCAP      (procedure in PROCED2.PRG)
|    |    └------BIPBIP      (procedure in PROCED2.PRG)
|    └------ODSAVE.PRG
|         |    OUTPUT.DBF (database)
|         |------BIPBIP      (procedure in PROCED2.PRG)
|         └------SAVED      (procedure in IDSAVE.PRG)
|              |    INPUT.DBF (database)
|              |    TEMPDATA.DBF (database)
|              |    OUTPUT.DBF (database)
|              |    TEMPSEL.DBF (database)
|              |    &FNAME (database)
|              |------BIPBIP      (procedure in PROCED2.PRG)
|              └------SAVED      (procedure in IDSAVE.PRG)
|                   |    INPUT.DBF (database)
|                   |    TEMPDATA.DBF (database)
|                   |    OUTPUT.DBF (database)
|                   |    TEMPSEL.DBF (database)
|                   |    &FNAME (database)
*** Truncating tree for recursive call to SAVED
|------MAIN3      (procedure in MAIN.PRG)
|    |------INSTAL.PRG
|    |    |    OUTPUT.DBF (database)
|    |    |    &FNAME (database)
|    |    └------BIPBIP      (procedure in PROCED2.PRG)
|    |------SEALS.PRG
|    |    |    &NAMEBT (database)
|    |    |------BIPBIP      (procedure in PROCED2.PRG)
|    |    └------SEAL      (procedure in SEALS.PRG)
|    |              SEAL.DBF (database)
|    |------LUBRIC.PRG
|    |    |------BIPBIP      (procedure in PROCED2.PRG)
|    |    |------OIL      (procedure in LUBRIC.PRG)
|    |    └------CHECK      (procedure in LUBRIC.PRG)
|    |         |------OIL      (procedure in LUBRIC.PRG)
|    |         └------GREASE      (procedure in LUBRIC.PRG)
|    |              |    SELECT.DBF (database)
|    |              |------GCODE      (procedure in LUBRIC.PRG)
|    |              |         GREASE.DBF (database)
|    |              └------OIL      (procedure in LUBRIC.PRG)
|    └------BEARFIT.PRG
|         |    SHAFTFIT.DBF (database)
|         |    SHAFTTOL.DBF (database)
|         |    HOUSETOL.DBF (database)
|         |------BIPBIP      (procedure in PROCED2.PRG)
|         |------INTERFIT      (procedure in BEARFIT.PRG)
|         |------DIA      (procedure in BEARFIT.PRG)
|         |------HOUSEFIT      (procedure in BEARFIT.PRG)
|         └------HDIA      (procedure in BEARFIT.PRG)
|------MAIN4      (procedure in MAIN.PRG)
```

```
 |     └──DBMAN.PRG
 |          |    SELECT.DBF (database)
 |          |    &BTNAME (database)
 |          ├────BIP      (procedure in DBMAN.PRG)
 |          |         FLD_DES.DBF (database)
 |          └────BIPBIP      (procedure in PROCED2.PRG)
 ├──MAIN5     (procedure in MAIN.PRG)
 |    ├──PRINTDB.PRG
 |    |       SELECT.DBF (database)
 |    |       &BTNAME (database)
 |    ├──PRINTID.PRG
 |    |       INPUT.DBF (database)
 |    |       TEMPDATA.DBF (database)
 |    ├──PRINTBS.PRG
 |    |       OUTPUT.DBF (database)
 |    |       &FNAME (database)
 |    └──PRINTOT.PRG
 ├──MAIN6     (procedure in MAIN.PRG)
 |    |  FINAL.DBF (database)
 |    |  TEMPSEL.DBF (database)
 |    └──GOODBY     (procedure in MAIN.PRG)
 └──HEAD.PRG
```

B.3 Database Structures

```
* 61 databases in the system

                           -->(Macro used for following databases)
   FINAL.DBF              |        ACBB1.DBF
   TEMPSEL.DBF            |        ACBB2.DBF
   TEMPLOC.DBF            |        ACBB3.DBF
   TSOTR1.DBF             |        ACTBBSD.DBF
   TSORT1.DBF             |        ACTBBDD.DBF
   TSOTR2.DBF             |        BRB.DBF
   TSORT2.DBF             |        CRB1.DBF
   TSORT3.DBF             |        CRB3.DBF
   TSORT4.DBF             |        CRBDR.DBF
   TSORT5.DBF             |        CRTB.DBF
   TSORT6.DBF             |        DGBB1.DBF
   OUTPUT.DBF             |        DGBB2.DBF
   TEMPCAP.DBF            |        FPCBB.DBF
   TEMPRPM.DBF            |        MB.DBF
   ONEREC.DBF             |        NRB1.DBF
   TEMP.DBF               |        NRB4.DBF
   TEMPBD.DBF             |        NRB5.DBF
   TEMPOD.DBF             |        NRTB.DBF
   TEMPW.DBF              |        SABB.DBF
   INPUT.DBF              |        SB.DBF
   LIFEHELP.DBF           |        SRB1.DBF
   TEMPDATA.DBF           |        SRTB.DBF
   TMPSEL.DBF             |        TBB1.DBF
   &FNAME                 |        TBB2.DBF
   &NAMEBT ----  --------|        TRB.DBF
   SEAL.DBF               |
   SELECT.DBF             |
   GREASE.DBF             |
   SHAFTFIT.DBF           |
   SHAFTTOL.DBF           |
   HOUSETOL.DBF           |
   &BTNAME --------------|
   FLD_DES.DBF
   SLHELP.DBF
   TEMPORL.DBF
   TEMPTL.DBF
   TEMPTL1.DBF
   TEMPCL.DBF
-----------------------------------------------------------------------
FINAL.DBF
Temporarily created database

Used by: FINAL_1          (procedure in PROCED2.PRG)
       : MAIN6            (procedure in MAIN.PRG)
       : ONLYRL1.PRG
       : ONLYTL1.PRG
       : COMLOAD1.PRG
---------------  ------------------------------------------------------

TEMPSEL.DBF
Temporarily created database

Used by: CAPSORT2         (procedure in PROCED2.PRG)
       : RPMSORT          (procedure in PROCED2.PRG)
```

```
Used by: CAPSORT2          (procedure in PROCED2.PRG)
       : RPMSORT           (procedure in PROCED2.PRG)
       : DIMSORT           (procedure in PROCED2.PRG)
       : MAIN6             (procedure in MAIN.PRG)
       : SAVED             (procedure in IDSAVE.PRG)
-----------------------------------------------------------
TEMPLOC.DBF
Temporarily created database

Used by: LOCAT_1           (procedure in PROCED2.PRG)
       : SORT_1            (procedure in PROCED2.PRG)
       : ONLYRL1.PRG
       : COMLOAD1.PRG
-----------------------------------------------------------
TSOTR1.DBF
Temporarily created database

Used by: SORT_1            (procedure in PROCED2.PRG)
-----------------------------------------------------------
TSORT1.DBF
Temporarily created database

Used by: SORT_1            (procedure in PROCED2.PRG)
-----------------------------------------------------------
TSOTR2.DBF
Temporarily created database

Used by: SORT_1            (procedure in PROCED2.PRG)
-----------------------------------------------------------
TSORT2.DBF
Temporarily created database

Used by: SORT_1            (procedure in PROCED2.PRG)
-----------------------------------------------------------
TSORT3.DBF
Temporarily created database

Used by: SORT_1            (procedure in PROCED2.PRG)
-----------------------------------------------------------
TSORT4.DBF
Temporarily created database

Used by: SORT_1            (procedure in PROCED2.PRG)
-----------------------------------------------------------
TSORT5.DBF
Temporarily created database

Used by: SORT_1            (procedure in PROCED2.PRG)
-----------------------------------------------------------
TSORT6.DBF
Temporarily created database

Used by: SORT_1            (procedure in PROCED2.PRG)
       : ONLYRL1.PRG
       : ONLYTL1.PRG
       : COMLOAD1.PRG
-----------------------------------------------------------
OUTPUT.DBF
```

Structure for database :
Number of data records : 12

Field	Field name	Type	Width	Dec	Start	End
1	OPNAME	Character	10		1	10
2	IPNAME	Character	10		11	20
3	BTNAME	Character	10		21	30
4	RPMVALUE	Numeric	6		31	36
5	TMAX	Numeric	3		37	39
6	TMIN	Numeric	3		40	42
7	SF1	Numeric	3	1	43	45
8	RLVALUE	Numeric	10		46	55
9	TLVALUE	Numeric	10		56	65
10	RLD	Character	1		66	66
11	PARTROT	Character	1		67	67
12	LOCFUNC	Character	2		68	69
** Total **			70			

This database appears to be associated with index file(s):
: OUTPUT1.IDX

```
Used by: FINAL_1        (procedure in PROCED2.PRG)
       : SELECT1.PRG
       : ODSAVE.PRG
       : INSTAL.PRG
       : PRINTBS.PRG
       : SAVED          (procedure in IDSAVE.PRG)
```

TEMPCAP.DBF
Temporarily created database

```
Used by: FINAL_1        (procedure in PROCED2.PRG)
       : CAPSORT1       (procedure in PROCED2.PRG)
       : CAPSORT2       (procedure in PROCED2.PRG)
       : RPMSORT        (procedure in PROCED2.PRG)
```

TEMPRPM.DBF
Temporarily created database

```
Used by: FINAL_1        (procedure in PROCED2.PRG)
       : RPMSORT        (procedure in PROCED2.PRG)
       : DIMSORT        (procedure in PROCED2.PRG)
```

ONEREC.DBF
Temporarily created database

```
Used by: CAPSORT1       (procedure in PROCED2.PRG)
```

TEMP.DBF
Temporarily created database

```
Used by: CAPSORT1       (procedure in PROCED2.PRG)
```

TEMPBD.DBF
Temporarily created database

```
Used by: DIMSORT        (procedure in PROCED2.PRG)
```

Temporarily created database

Used by: DIMSORT (procedure in PROCED2.PRG)

TEMPW.DBF
Temporarily created database

Used by: DIMSORT (procedure in PROCED2.PRG)

INPUT.DBF
Structure for database :
Number of data records : 11

Field	Field name	Type	Width	Dec	Start	End
1	IPNAME	Character	10		1	10
2	NRPM	Numeric	1		11	11
3	RPMVALUE	Numeric	6		12	17
4	MEANRPM	Numeric	6		18	23
5	RPM1	Numeric	6		24	29
6	RPM2	Numeric	6		30	35
7	RPM3	Numeric	6		36	41
8	RPM4	Numeric	6		42	47
9	RPM5	Numeric	6		48	53
10	RPM6	Numeric	6		54	59
11	RPM7	Numeric	6		60	65
12	RPM8	Numeric	6		66	71
13	RPM9	Numeric	6		72	77
14	PER1	Numeric	2		78	79
15	PER2	Numeric	2		80	81
16	PER3	Numeric	2		82	83
17	PER4	Numeric	2		84	85
18	PER5	Numeric	2		86	87
19	PER6	Numeric	2		88	89
20	PER7	Numeric	2		90	91
21	PER8	Numeric	2		92	93
22	PER9	Numeric	2		94	95
23	NRL	Numeric	1		96	96
24	RLVALUE	Numeric	10		97	106
25	MEANRL	Numeric	10		107	116
26	RL1	Numeric	10		117	126
27	RL2	Numeric	10		127	136
28	RL3	Numeric	10		137	146
29	RL4	Numeric	10		147	156
30	RL5	Numeric	10		157	166
31	RL6	Numeric	10		167	176
32	RL7	Numeric	10		177	186
33	RL8	Numeric	10		187	196
34	RL9	Numeric	10		197	206
35	PR1	Numeric	2		207	208
36	PR2	Numeric	2		209	210
37	PR3	Numeric	2		211	212
38	PR4	Numeric	2		213	214
39	PR5	Numeric	2		215	216
40	PR6	Numeric	2		217	218
41	PR7	Numeric	2		219	220
42	PR8	Numeric	2		221	222
43	PR9	Numeric	2		223	224
44	RLMAX	Numeric	10		225	234
45	RLMIN	Numeric	10		235	244

46	RLCON	Numeric	10		245	254
47	RLROT	Numeric	10		255	264
48	RLD	Character	1		265	265
49	NTL	Numeric	1		266	266
50	TLVALUE	Numeric	10		267	276
51	MEANTL	Numeric	10		277	286
52	TL1	Numeric	10		287	296
53	TL2	Numeric	10		297	306
54	TL3	Numeric	10		307	316
55	TL4	Numeric	10		317	326
56	TL5	Numeric	10		327	336
57	TL6	Numeric	10		337	346
58	TL7	Numeric	10		347	356
59	TL8	Numeric	10		357	366
60	TL9	Numeric	10		367	376
61	PT1	Numeric	2		377	378
62	PT2	Numeric	2		379	380
63	PT3	Numeric	2		381	382
64	PT4	Numeric	2		383	384
65	PT5	Numeric	2		385	386
66	PT6	Numeric	2		387	388
67	PT7	Numeric	2		389	390
68	PT8	Numeric	2		391	392
69	PT9	Numeric	2		393	394
70	TLMAX	Numeric	10		395	404
71	TLMIN	Numeric	10		405	414
72	TLCON	Numeric	10		415	424
73	TLROT	Numeric	10		425	434
74	TLD	Character	1		435	435
75	SHOK	Numeric	3	1	436	438
76	RLB	Numeric	2		439	440
77	A_1	Numeric	4	2	441	444
78	LHR	Numeric	7		445	451
79	LKM	Numeric	4	2	452	455
80	DIA	Numeric	4	2	456	459
81	LIFEIS	Numeric	8		460	467
82	TMPMAX	Numeric	3		468	470
83	TMPMIN	Numeric	3		471	473
84	FTEMP	Numeric	4	2	474	477
85	OP1	Numeric	1		478	478
86	OP2	Numeric	1		479	479
87	OP3	Numeric	1		480	480
88	OP4	Numeric	1		481	481
89	OP5	Numeric	1		482	482
90	OP6	Numeric	1		483	483
91	OP7	Numeric	1		484	484
92	OP8	Numeric	1		485	485
93	OP9	Numeric	1		486	486
94	PARTROT	Character	1		487	487
95	LOCFUNC	Character	2		488	489
96	BDMAX	Numeric	4		490	493
97	BDMIN	Numeric	4		494	497
98	ODMAX	Numeric	4		498	501
99	ODMIN	Numeric	4		502	505
100	WMAX	Numeric	3		506	508
101	WMIN	Numeric	3		509	511
** Total **			512			

```
This database appears to be associated with index file(s):
      : INPUT1.IDX

This database appears to be associated with multiple index file(s):
      : INPUT.MDX

Used by: RELIBITY.PRG
      : TEMPAR.PRG
      : DIMEN1.PRG
      : OPCON1.PRG
      : DISPDATA.PRG
      : IDSAVE.PRG
      : SELECT1.PRG
      : PRINTID.PRG
      : SPD              (procedure in SPEED.PRG)
      : LOADTYPE         (procedure in LOAD1.PRG)
      : GETLIFE          (procedure in LIFE1.PRG)
      : SAVED            (procedure in IDSAVE.PRG)
      : SLOAD            (procedure in SUDDEN.PRG)
--------------------------------------------------------------------------
LIFEHELP.DBF
Structure for database :
Number of data records :   123
Field  Field name  Type        Width    Dec    Start     End
    1  USE         Character      44               1      44
    2  OPER_       Character       5              45      49
    3  HOURS       Character       7              50      56
** Total **                       57

Used by: GETLIFE         (procedure in LIFE1.PRG)
--------------------------------------------------------------------------
TEMPDATA.DBF
Temporarily created database

Used by: DISPDATA.PRG
      : PRINTID.PRG
      : SAVED            (procedure in IDSAVE.PRG)
--------------------------------------------------------------------------
TMPSEL.DBF
Temporarily created database

Used by: SELECT1.PRG
--------------------------------------------------------------------------
&FNAME is a macro used for database
Temporarily created database

This database appears to be associated with report form(s):
      : TEST.FRG

Used by: INSTAL.PRG
      : PRINTBS.PRG
      : SAVED            (procedure in IDSAVE.PRG)
--------------------------------------------------------------------------
&NAMEBT is a macro used for a group of bearing databases (see database list

Used by: SEALS.PRG
      : &NAME (macro used for a group of PRG files; see PRG file list)
```

Structures of databases are as follows :

ACBB1.DBF
Structure for database:
Number of data records: 49

Field	Field Name	Type	Width	Dec	Index
1	TYPE	Character	1		N
2	B_NUMBER	Character	8		N
3	COMPANY	Character	5		N
4	BORE_DIA	Numeric	3		N
5	OUTER_DIA	Numeric	3		N
6	WIDTH	Numeric	3		N
7	C	Numeric	6		N
8	CO	Numeric	6		N
9	RPM_GRES	Numeric	6		N
10	RPM_OIL	Numeric	6		N
11	MASS	Numeric	6	3	N
** Total **			54		

ACBB2.DBF
Structure for database:
Number of data records: 47

Field	Field Name	Type	Width	Dec	Index
1	TYPE	Character	1		N
2	B_NUMBER	Character	8		N
3	COMPANY	Character	5		N
4	BORE_DIA	Numeric	3		N
5	OUTER_DIA	Numeric	3		N
6	WIDTH	Numeric	3		N
7	C	Numeric	6		N
8	CO	Numeric	6		N
9	RPM_GRES	Numeric	6		N
10	RPM_OIL	Numeric	6		N
11	MASS	Numeric	6	3	N
** Total **			54		

ACBB3.DBF
Structure for database:
Number of data records: 42

Field	Field Name	Type	Width	Dec	Index
1	TYPE	Character	1		N
2	B_NUMBER	Character	8		N
3	COMPANY	Character	5		N
4	BORE_DIA	Numeric	3		N
5	OUTER_DIA	Numeric	3		N
6	WIDTH	Numeric	4	1	N
7	C	Numeric	6		N
8	CO	Numeric	6		N
9	RPM_GRES	Numeric	6		N
10	RPM_OIL	Numeric	6		N
11	MASS	Numeric	6	3	N
** Total **			55		

ACTBBSD.DBF
Structure for database:
Number of data records: 34

Field	Field Name	Type	Width	Dec	Index
1	TYPE	Character	1		N

2	B_NUMBER	Character	10		N
3	COMPANY	Character	3		N
4	BORE_DIA	Numeric	3		N
5	OUTER_DIA	Numeric	3		N
6	WIDTH	Numeric	2		N
7	A	Numeric	5	1	N
8	C	Numeric	6		N
9	CO	Numeric	6		N
10	MALOAD	Numeric	3		N
11	RPM_OIL	Numeric	4		N
12	RPM_GRES	Numeric	4		N
13	PRELOAD	Numeric	4	1	N
14	FR_MOMT	Numeric	4		N
15	MASS	Numeric	4	2	N
** Total **			63		

ACTBBDD.DBF

Structure for database:

Number of data records: 52

Field	Field Name	Type	Width	Dec	Index
1	TYPE	Character	1		N
2	B_NUMBER	Character	9		N
3	COMPANY	Character	3		N
4	BORE_DIA	Numeric	3		N
5	OUTER_DIA	Numeric	3		N
6	WIDTH	Numeric	3		N
7	C	Numeric	6		N
8	CO	Numeric	6		N
9	RPM_GRES	Numeric	5		N
10	RPM_OIL	Numeric	5		N
11	MASS	Numeric	5	2	N
** Total **			50		

BRB.DBF

Structure for database:

Number of data records: 78

Field	Field Name	Type	Width	Dec	Index
1	TYPE	Character	1		N
2	B_NUMBER	Character	7		N
3	DSGN_TB	Character	9		N
4	COMPANY	Character	3		N
5	BORE_DIA	Numeric	3		N
6	OUTER_DIA	Numeric	3		N
7	WIDTH	Numeric	2		N
8	C	Numeric	7		N
9	CO	Numeric	7		N
10	RPM_GRES	Numeric	4		N
11	RPM_OIL	Numeric	4		N
12	MASS	Numeric	5	2	N
** Total **			56		

CRB1.DBF

Structure for database:

Number of data records: 234

Field	Field Name	Type	Width	Dec	Index
1	TYPE	Character	1		N
2	B_NUMBER	Character	10		N
3	COMPANY	Character	3		N

```
     4   BORE_DIA     Numeric         3                 N
     5   OUTER_DIA    Numeric         4                 N
     6   WIDTH        Numeric         3                 N
     7   C            Numeric         7                 N
     8   CO           Numeric         7                 N
     9   RPM_GRES     Numeric         5                 N
    10   RPM_OIL      Numeric         5                 N
    11   MASS         Numeric         7      3          N
** Total **                          56
-------------------------------------------------------
CRB3.DBF
Structure for database:
Number of data records:    206
Field   Field Name   Type         Width     Dec     Index
     1   TYPE         Character       1                 N
     2   B_NUMBER     Character       7                 N
     3   COMPANY      Character       3                 N
     4   BORE_DIA     Numeric         3                 N
     5   OUTER_DIA    Numeric         3                 N
     6   WIDTH        Numeric         3                 N
     7   C            Numeric         7                 N
     8   CO           Numeric         7                 N
     9   RPM_OIL      Numeric         5                 N
    10   RPM_GRES     Numeric         5                 N
    11   MASS         Numeric         6      3          N
** Total **                          51
---------------------------------------------------
CRBDR.DBF
Structure for database:
Number of data records:  60
Field   Field Name   Type         Width     Dec     Index
     1   TYPE         Character       1                 N
     2   B_NUMBER     Character      12                 N
     3   DSGN_SB      Character      11                 N
     4   COMPANY      Character       3                 N
     5   BORE_DIA     Numeric         3                 N
     6   OUTER_DIA    Numeric         3                 N
     7   WIDTH        Numeric         3                 N
     8   C            Numeric         7                 N
     9   CO           Numeric         7                 N
    10   RPM_GRES     Numeric         5                 N
    11   RPM_OIL      Numeric         5                 N
    12   MASS         Numeric         5      2          N
** Total **                          66
---------------- ------------------------------------
CRTB.DBF
Structure for database:
Number of data records:       88
Field   Field Name   Type         Width     Dec     Index
     1   TYPE         Character       1                 N
     2   B_NUMBER     Character       9                 N
     3   DSGN_ASSY    Character      10                 N
     4   COMPANY      Character       3                 N
     5   BORE_DIA     Numeric         3                 N
     6   OUTER_DIA    Numeric         3                 N
     7   WIDTH        Numeric         3                 N
     8   C            Numeric         7                 N
     9   CO           Numeric
```

10	A	Numeric	6	2	N
11	RPM_GRES	Numeric	4		N
12	RPM_OIL	Numeric	4		N
13	MASS	Numeric	6	2	N
** Total **			68		

DGBB1.DBF
Structure for database:
Number of data records: 214

Field	Field Name	Type	Width	Dec	Index
1	TYPE	Character	1		N
2	B_NUMBER	Character	9		N
3	COMPANY	Character	5		N
4	BORE_DIA	Numeric	3		N
5	OUTER_DIA	Numeric	3		N
6	WIDTH	Numeric	3		N
7	C	Numeric	6		N
8	CO	Numeric	6		N
9	RPM_GRES	Numeric	6		N
10	RPM_OIL	Numeric	6		N
11	MASS	Numeric	6	3	N
12	Z	Logical	1		N
13	ZZ	Logical	1		N
14	N	Logical	1		N
15	K	Logical	1		N
16	RS	Logical	1		N
17	RS2	Logical	1		N
18	NR	Logical	1		N
19	ZNR	Logical	1		N
** Total **			63		

DGBB2.DBF
Structure for database:
Number of data records: 31

Field	Field Name	Type	Width	Dec	Index
1	TYPE	Character	1		N
2	B_NUMBER	Character	8		N
3	COMPANY	Character	5		N
4	BORE_DIA	Numeric	3		N
5	OUTER_DIA	Numeric	3		N
6	WIDTH	Numeric	3		N
7	C	Numeric	6		N
8	CO	Numeric	6		N
9	RPM_GRES	Numeric	6		N
10	RPM_OIL	Numeric	6		N
11	MASS	Numeric	6	3	N
** Total **			54		

FPCBB.DBF
Structure for database:
Number of data records: 39

Field	Field Name	Type	Width	Dec	Index
1	TYPE	Character	1		N
2	B_NUMBER	Character	8		N
3	COMPANY	Character	5		N
4	BORE_DIA	Numeric	3		N
5	OUTER_DIA	Numeric	3		N
6	WIDTH	Numeric	3		N

```
    7   C                  Numeric          6                   N
    8   CO                 Numeric          6                   N
    9   RPM_GRES           Numeric          6                   N
   10   RPM_OIL            Numeric          6                   N
   11   MASS               Numeric          6         3         N
** Total **                                54
--------------------------------------------------------------------
MB.DBF
Structure for database:
Number of data records:   17
Field   Field Name   Type         Width      Dec      Index
    1   TYPE         Character        1                   N
    2   B_NUMBER     Character        7                   N
    3   COMPANY      Character        3                   N
    4   BORE_DIA     Numeric          2                   N
    5   OUTER_DIA    Numeric          2                   N
    6   WIDTH        Numeric          2                   N
    7   C            Numeric          5                   N
    8   CO           Numeric          5                   N
    9   RPM_OIL      Numeric          5                   N
   10   RPM_GRES     Numeric          5                   N
   11   MASS         Numeric          5         3         N
** Total **                          43
--------------------------------------------------------------------
NRB1.DBF
Structure for database:
Number of data records:      287
Field   Field Name   Type         Width      Dec      Index
    1   TYPE         Character        1                   N
    2   B_NUMBER     Character       10                   N
    3   COMPANY      Character        5                   N
    4   BORE_DIA     Numeric          4                   N
    5   OUTER_DIA    Numeric          4                   N
    6   WIDTH        Numeric          4                   N
    7   C            Numeric          8                   N
    8   CO           Numeric          8                   N
    9   RPM_GRES     Numeric          9                   N
   10   RPM_OIL      Numeric          9                   N
   11   MASS         Numeric          6         3         N
** Total **                          69
--------------------------------------------------------------------
NRB4.DBF
Structure for database:
Number of data records:        16
Field   Field Name   Type         Width      Dec      Index
    1   TYPE         Character        1                   N
    2   B_NUMBER     Character        9                   N
    3   COMPANY      Character        5                   N
    4   BORE_DIA     Numeric          4                   N
    5   OUTER_DIA    Numeric          4                   N
    6   WIDTH        Numeric          3                   N
    7   C_R          Numeric          6                   N
    8   CO_R         Numeric          6                   N
    9   C_A          Numeric          5                   N
   10   CO_A         Numeric          5                   N
   11   RPM_GRES     Numeric          6                   N
   12   RPM_OIL      Numeric          6                   N
   13   MASS         Numeric          6         3         N
```

NRB5.DBF
Structure for database:
Number of data records: 13

Field	Field Name	Type	Width	Dec	Index
1	TYPE	Character	1		N
2	B_NUMBER	Character	9		N
3	COMPANY	Character	5		N
4	BORE_DIA	Numeric	4		N
5	OUTER_DIA	Numeric	4		N
6	WIDTH	Numeric	3		N
7	C_R	Numeric	6		N
8	CO_R	Numeric	6		N
9	C_A	Numeric	5		N
10	CO_A	Numeric	5		N
11	RPM_GRES	Numeric	6		N
12	RPM_OIL	Numeric	6		N
13	MASS	Numeric	6	3	N
14	A	Numeric	4	1	N
** Total **			71		

NRTB.DBF
Structure for database:
Number of data records: 26

Field	Field Name	Type	Width	Dec	Index
1	TYPE	Character	1		N
2	B_NUMBER	Character	11		N
3	DSGN_SH_W	Character	7		N
4	DSGN_HO_W	Character	7		N
5	DSGN_RA_W	Character	11		N
6	DSGN_TH_W	Character	11		N
7	COMPANY	Character	3		N
8	BORE_DIA	Numeric	3		N
9	OUTER_DIA	Numeric	3		N
10	WIDTH	Numeric	2		N
11	B_MM	Numeric	4	2	N
12	C	Numeric	6		N
13	CO	Numeric	6		N
14	RPM_GRES	Numeric	4		N
15	RPM_OIL	Numeric	4		N
** Total **			84		

SABB.DBF
Structure for database:
Number of data records: 116

Field	Field Name	Type	Width	Dec	Index
1	TYPE	Character	1		N
2	B_NUMBER	Character	11		N
3	DSGN_TB	Character	5		N
4	COMPANY	Character	3		N
5	BORE_DIA	Numeric	3		N
6	OUTER_DIA	Numeric	3		N
7	WIDTH	Numeric	3		N
8	C	Numeric	6		N
9	CO	Numeric	6		N
10	RPM_OIL	Numeric	6		N

Field	Field Name	Type	Width	Dec	Index
12	MASS	Numeric	6	3	N
13	E	Numeric	4	2	N
14	Y1	Numeric	3	1	N
15	Y2	Numeric	3	1	N
16	Y0	Numeric	3	1	N
** Total **			73		

SB.DBF
Structure for database:
Number of data records: 86

Field	Field Name	Type	Width	Dec	Index
1	TYPE	Character	1		N
2	B_NUMBER	Character	17		N
3	COMPANY	Character	3		N
4	BORE_DIA	Numeric	3		N
5	OUTER_DIA	Numeric	3		N
6	WIDTH	Numeric	3		N
7	C	Numeric	6		N
8	CO	Numeric	6		N
9	RPM_GRES	Numeric	5		N
10	RPM_OIL	Numeric	5		N
11	MASS	Numeric	4	2	N
** Total **			57		

SRB1.DBF
Structure for database:
Number of data records: 167

Field	Field Name	Type	Width	Dec	Index
1	TYPE	Character	1		N
2	B_NUMBER	Character	8		N
3	COMPANY	Character	3		N
4	BORE_DIA	Numeric	4		N
5	OUTER_DIA	Numeric	4		N
6	WIDTH	Numeric	3		N
7	C	Numeric	8		N
8	CO	Numeric	8		N
9	RPM_OIL	Numeric	4		N
10	RPM_GRES	Numeric	4		N
11	MASS	Numeric	7	2	N
12	K	Logical	1		N
13	W33	Logical	1		N
14	E	Numeric	4	2	N
15	Y1	Numeric	3	1	N
16	Y2	Numeric	3	1	N
17	Y0	Numeric	3	1	N
** Total **			70		

SRTB.DBF
Structure for database:
Number of data records: 91

Field	Field Name	Type	Width	Dec	Index
1	TYPE	Character	1		N
2	B_NUMBER	Character	11		N
3	COMPANY	Character	3		N
4	BORE_DIA	Numeric	3		N
5	OUTER_DIA	Numeric	4		N
6	WIDTH	Numeric	3		N
7	C	Numeric	8		N

```
      8   CO           Numeric          8                  N
      9   A            Numeric          7                  N
     10   RPM_OIL      Numeric          4                  N
     11   RPM_GRES     Numeric          2                  N
     12   MASS         Numeric          7        2         N
** Total **                            62
------------------------------------------------------------
TBB1.DBF
Structure for database:
Number of data records:       124
Field   Field Name   Type           Width     Dec    Index
      1   TYPE         Character        1                  N
      2   B_NUMBER     Character        7                  N
      3   DSGN_SPH     Character        6                  N
      4   COMPANY      Character        3                  N
      5   BORE_DIA     Numeric          3                  N
      6   OUTER_DIA    Numeric          3                  N
      7   WIDTH        Numeric          3                  N
      8   C            Numeric          6                  N
      9   CO           Numeric          7                  N
     10   A            Numeric          8        2         N
     11   RPM_GRES     Numeric          4                  N
     12   RPM_OIL      Numeric          4                  N
     13   MASS         Numeric          5        2         N
** Total **                            61
------------------------------------------------------------
TBB2.DBF
Structure for database:
Number of data records:        49
Date of last update   : 09/10/95
Field   Field Name   Type           Width     Dec    Index
      1   TYPE         Character        1                  N
      2   B_NUMBER     Character        7                  N
      3   DSGN_SPH     Character        5                  N
      4   COMPANY      Character        3                  N
      5   BORE_DIA     Numeric          3                  N
      6   OUTER_DIA    Numeric          3                  N
      7   WIDTH        Numeric          3                  N
      8   C            Numeric          6                  N
      9   CO           Numeric          7                  N
     10   A            Numeric          8        2         N
     11   RPM_GRES     Numeric          4                  N
     12   RPM_OIL      Numeric          4                  N
     13   MASS         Numeric          5        2         N
** Total **                            60
------------------------------------------------------------
TRB.DBF
Structure for database:
Number of data records:       102
Field   Field Name   Type           Width     Dec    Index
      1   TYPE         Character        1                  N
      2   B_NUMBER     Character        8                  N
      3   COMPANY      Character        3                  N
      4   BORE_DIA     Numeric          3                  N
      5   OUTER_DIA    Numeric          3                  N
      6   WIDTH        Numeric          5        2         N
      7   C            Numeric          7                  N
      8   CO           Numeric          7                  N
```

9	RPM_GRES	Numeric	4		N
10	RPM_OIL	Numeric	5		N
11	MASS	Numeric	5	2	N
12	E	Numeric	4	2	N
13	Y2	Numeric	3	1	N
14	Y0	Numeric	3	1	N
** Total **			62		

SEAL.DBF
Structure for database :
Number of data records : 27

Field	Field name	Type	Width	Dec	Start	End
1	SEAL_TYPE	Character	18		1	18
2	OIL_LUB	Character	3		19	21
3	GRE_LUB	Character	3		22	24
4	SPEED	Character	5		25	29
5	TEMP	Character	4		30	33
6	DUST	Character	8		34	41
7	MOISTURE	Character	8		42	49
8	INSTAL	Character	8		50	57
9	SPACE	Character	8		58	65
10	OTHERS	Character	30		66	95
** Total **			96			

Used by: SEAL (procedure in SEALS.PRG)

SELECT.DBF
Structure for database :
Number of data records : 27

Field	Field name	Type	Width	Dec	Start	End
1	DBNAME	Character	10		1	10
2	BEARNAME	Character	25		11	35
3	ORL	Numeric	1		36	36
4	OTL	Numeric	1		37	37
5	CL	Numeric	1		38	38
6	V1	Numeric	1		39	39
7	V2	Numeric	1		40	40
8	V3	Numeric	1		41	41
9	V4	Numeric	1		42	42
10	V5	Numeric	1		43	43
11	V6	Numeric	1		44	44
12	V7	Numeric	1		45	45
13	V8	Numeric	1		46	46
14	WEIGHTAGE	Numeric	3		47	49
15	RLCAP	Numeric	1		50	50
16	TLCAP	Numeric	1		51	51
17	CLCAP	Numeric	1		52	52
18	SLCAP	Numeric	1		53	53
19	LRATIO	Numeric	4	2	54	57
20	TLDIR	Character	1		58	58
21	LOCAT	Numeric	1		59	59
22	MAXTEMP	Numeric	3		60	62
23	MAXRPM	Numeric	5		63	67
24	FRELUB	Numeric	2		68	69
** Total **			70			

Used by: DBMAN.PRG

```
      : ONLYRL1.PRG
      : ONLYTL1.PRG
      : COMLOAD1.PRG
      : GREASE            (procedure in LUBRIC.PRG)
------------------------------------------------------------------------
GREASE.DBF
Structure for database :
Number of data records :     7
Field  Field name  Type         Width    Dec    Start     End
    1  CODE        Character        8               1       8
    2  THICKNER    Character       17               9      25
    3  BASE_OIL    Character       12              26      37
    4  TEMP_MIN    Numeric          3              38      40
    5  TEMP_MAX    Numeric          3              41      43
    6  RUST_PROT   Character        3              44      46
    7  COST        Character        6              47      52
** Total **                        53

Used by: GCODE            (procedure in LUBRIC.PRG)
------------------------------------------------------------------------
SHAFTFIT.DBF
Structure for database :
Number of data records :   25
Field  Field name  Type         Width    Dec    Start     End
    1  BTNAME      Character       10               1      10
    2  X1          Character        2              11      12
    3  X2          Character        2              13      14
    4  X3          Character        2              15      16
    5  X4          Character        2              17      18
    6  X5          Character        2              19      20
    7  X6          Character        2              21      22
    8  X7          Character        2              23      24
    9  X8          Character        2              25      26
   10  Y1          Character        2              27      28
   11  Y2          Character        2              29      30
   12  Y3          Character        2              31      32
   13  Y4          Character        2              33      34
   14  Y5          Character        2              35      36
   15  Y6          Character        2              37      38
   16  Y7          Character        2              39      40
   17  Y8          Character        2              41      42
   18  Z1          Character        2              43      44
   19  Z2          Character        2              45      46
   20  Z3          Character        2              47      48
   21  Z4          Character        2              49      50
   22  Z5          Character        2              51      52
   23  Z6          Character        2              53      54
   24  Z7          Character        2              55      56
   25  Z8          Character        2              57      58
   26  X9          Character        2              59      60
   27  Y9          Character        2              61      62
   28  Z9          Character        2              63      64
** Total **                        65

Used by: BEARFIT.PRG
------------------------------------------------------------------------
SHAFTTOL.DBF
Structure for database :
```

Number of data records : 14

Field	Field name	Type	Width	Dec	Start	End
1	DES	Character	3		1	3
2	SD1	Character	7		4	10
3	SD2	Character	7		11	17
4	SD3	Character	7		18	24
5	SD4	Character	7		25	31
6	SD5	Character	7		32	38
7	SD6	Character	7		39	45
8	SD7	Character	7		46	52
9	SD8	Character	8		53	60
10	SD9	Character	8		61	68
11	SD10	Character	9		69	77
12	SD11	Character	9		78	86
13	SD12	Character	9		87	95
14	SD13	Character	9		96	104
15	SD14	Character	9		105	113
16	SD15	Character	9		114	122
17	SD16	Character	9		123	131
** Total **			132			

Used by: BEARFIT.PRG

HOUSETOL.DBF
Structure for database :
Number of data records : 6

Field	Field name	Type	Width	Dec	Start	End
1	DES	Character	3		1	3
2	HD1	Character	7		4	10
3	HD2	Character	7		11	17
4	HD3	Character	7		18	24
5	HD4	Character	7		25	31
6	HD5	Character	7		32	38
7	HD6	Character	7		39	45
8	HD7	Character	7		46	52
9	HD8	Character	8		53	60
10	HD9	Character	8		61	68
11	HD10	Character	9		69	77
12	HD11	Character	9		78	86
13	HD12	Character	9		87	95
14	HD13	Character	9		96	104
15	HD14	Character	9		105	113
16	HD15	Character	9		114	122
17	HD16	Character	9		123	131
** Total **			132			

Used by: BEARFIT.PRG

&BTNAME is a macro used for same databases shown in &NAMEBT

This database appears to be associated with report form(s):
: TEST.FRG

Used by: DBMAN.PRG
: PRINTDB.PRG

FLD_DES.DBF
Structure for database :

```
Number of data records :    16
Field  Field name  Type          Width    Dec    Start     End
    1  FLDNAME     Character        10                1      10
    2  DESCRIP     Character        40               11      50
** Total **                         51

Used by: BIP              (procedure in DBMAN.PRG)
----------------- ----------------------------------------------
SLHELP.DBF
Structure for database :
Number of data records :    33
Field  Field name  Type          Width    Dec    Start     End
    1  USE         Character        45                1      45
    2  DUTY_TYPE   Character        13               46      58
** Total **                         59

Used by: SLOAD            (procedure in SUDDEN.PRG)
----------------------------------------------------------------
TEMPORL.DBF
Temporarily created database

Used by: ONLYRL1.PRG
----------------------------------------------------------------
TEMPTL.DBF
Temporarily created database

Used by: ONLYTL1.PRG
----------------------------------------------------------------
TEMPTL1.DBF
Structure for database :
Number of data records :    16
Field  Field name  Type          Width    Dec    Start     End
    1  DBNAME      Character        10                1      10
    2  BEARNAME    Character        25               11      35
    3  ORL         Numeric           1               36      36
    4  OTL         Numeric           1               37      37
    5  CL          Numeric           1               38      38
    6  V1          Numeric           1               39      39
    7  V2          Numeric           1               40      40
    8  V3          Numeric           1               41      41
    9  V4          Numeric           1               42      42
   10  V5          Numeric           1               43      43
   11  V6          Numeric           1               44      44
   12  V7          Numeric           1               45      45
   13  V8          Numeric           1               46      46
   14  WEIGHTAGE   Numeric           3               47      49
   15  RLCAP       Numeric           1               50      50
   16  TLCAP       Numeric           1               51      51
   17  CLCAP       Numeric           1               52      52
   18  SLCAP       Numeric           1               53      53
   19  LRATIO      Numeric           4      2        54      57
   20  TLDIR       Character         1               58      58
   21  LOCAT       Numeric           1               59      59
   22  MAXTEMP     Numeric           3               60      62
   23  MAXRPM      Numeric           5               63      67
   24  FRELUB      Numeric           2               68      69
** Total **                         70
```

```
Used by: ONLYTL1.PRG
-----------------------------------------------------------------------
TEMPCL.DBF
Temporarily created database

Used by: COMLOAD1.PRG
-----------------------------------------------------------------------
```

B.4 System Files

```
---------------------------------------------------------------------------------
Programs and procedures:
--------------------------
  &NAME ---------------------------------->(Macro used for following PRG fi
                                                              { ACBB1.PRG
  BEARFIT.PRG                                                   ACBB2.PRG
  BIP             (procedure in DBMAN.PRG)                      ACBB3.PRG
  BIPBIP          (procedure in PROCED2.PRG)                    ACTBBSD.PRG
  CAPSORT1        (procedure in PROCED2.PRG)                    ACTBBDD.PRG
  CAPSORT2        (procedure in PROCED2.PRG)                    BRB.PRG
  CHECK           (procedure in LUBRIC.PRG)                     CRB1.PRG
  COMLOAD1.PRG                                                  CRB3.PRG
  CON             (procedure in OPCON1.PRG)                     CRBDR.PRG
  DBMAN.PRG                                                     CRTB.PRG
  DECOR           (procedure in LOAD1.PRG)                      DGBB1.PRG
  DIA             (procedure in BEARFIT.PRG)                    DGBB2.PRG
  DIMEN1.PRG                                                    FPCBB.PRG
  DIMSORT         (procedure in PROCED2.PRG)                    MB.PRG
  DISPDATA.PRG                                                  NRB1.PRG
  ERROR1          (procedure in PROCED2.PRG)                    NRB4.PRG
  ERROR2          (procedure in PROCED2.PRG)                    NRB5.PRG
  ERROR3          (procedure in PROCED2.PRG)                    NRTB.PRG
  ERROR4          (procedure in PROCED2.PRG)                    SABB.PRG
  ERROR5          (procedure in PROCED2.PRG)                    SB.PRG
  FINAL_1         (procedure in PROCED2.PRG)                    SRB1.PRG
  GCODE           (procedure in LUBRIC.PRG)                     SRTB.PRG
  GETLIFE         (procedure in LIFE1.PRG)                      TBB1.PRG
  GOODBY          (procedure in MAIN.PRG)                       TBB2.PRG
  GREASE          (procedure in LUBRIC.PRG)                     TRB.PRG }
  HDIA            (procedure in BEARFIT.PRG)
  HEAD.PRG
  HOUSEFIT        (procedure in BEARFIT.PRG)
  IDSAVE.PRG
  INSTAL.PRG
  INTERFIT        (procedure in BEARFIT.PRG)
  LIFE1.PRG
  LOAD1.PRG
  LOADTYPE        (procedure in LOAD1.PRG)
  LOC             (procedure in OPCON1.PRG)
  LOCAT_1         (procedure in PROCED2.PRG)
  LUBRIC.PRG
  MAIN.PRG
  MAIN1           (procedure in MAIN.PRG)
  MAIN2           (procedure in MAIN.PRG)
  MAIN3           (procedure in MAIN.PRG)
  MAIN4           (procedure in MAIN.PRG)
  MAIN5           (procedure in MAIN.PRG)
  MAIN6           (procedure in MAIN.PRG)
  ODSAVE.PRG
  OIL             (procedure in LUBRIC.PRG)
  ONLYRL1.PRG
  ONLYTL1.PRG
  OPCON1.PRG
                             in TEST.PRG)
```

```
  PGPLAIN               (procedure in TEST.FRG)
  POC                   (procedure in OPCON1.PRG)
  PRINTBS.PRG
  PRINTDB.PRG
  PRINTID.PRG
  PRINTOT.PRG
  PRNABORT              (procedure in TEST.FRG)
  RELIBITY.PRG
  RESET                 (procedure in TEST.FRG)
  RLDIR                 (procedure in LOAD1.PRG)
  RLOAD                 (procedure in LOAD1.PRG)
  ROT                   (procedure in OPCON1.PRG)
  RPMSORT               (procedure in PROCED2.PRG)
  RSUMM                 (procedure in TEST.FRG)
  SAVED                 (procedure in IDSAVE.PRG)
  SEAL                  (procedure in SEALS.PRG)
  SEALS.PRG
  SELECT1.PRG
  SELECT2.PRG
  SELECT3.PRG
  SELECT4.PRG
  SHOWCAP               (procedure in PROCED2.PRG)
  SLOAD                 (procedure in SUDDEN.PRG)
  SORT_1                (procedure in PROCED2.PRG)
  SPD                   (procedure in SPEED.PRG)
  SPEED.PRG
  SUDDEN.PRG
  TEMPAR.PRG
  TEST.FRG
  TEST.FRG
  TLDIR                 (procedure in LOAD1.PRG)
  TLOAD                 (procedure in LOAD1.PRG)
  UPD_VARS              (procedure in TEST.FRG)
  VRLOAD                (procedure in PROCED2.PRG)
  __DETAIL              (procedure in TEST.FRG)

Procedure files:
  PROCED2.PRG
  MAIN.PRG
  SPEED.PRG
  LOAD1.PRG
  LIFE1.PRG
  OPCON1.PRG
  IDSAVE.PRG
  ODSAVE.PRG
  SEALS.PRG
  LUBRIC.PRG
  BEARFIT.PRG
  DBMAN.PRG
  SUDDEN.PRG
  TEST.FRG

Index files:
  INPUT1.IDX
```

```
  INPUT1.NDX
  OUTPUT1.IDX
  OUTPUT1.NDX

Multiple index files:
  INPUT.MDX

Report forms:
  TEST.FRG

Database files are shown in Database structure summary
```


```
Database files are shown in Database structure summary
```